HETEROGENEOUS IT INNOVATION

DEVELOPING INDUSTRIAL ARCHITECTURAL KNOWLEDGE

Magnus Andersson

GÖTEBORG UNIVERSITY

Department of Applied Information Technology
IT-University of Göteborg
Göteborg University
Box 8718, SE-40275 Göteborg, Sweden
www.ituniv.se | www.gu.se | www.chalmers.se
magnus.andersson@viktoria.se

ABSTRACT

Multiple information technologies are converging. Crucial to organizations' relentless struggle to remain competitive, IT innovation processes must now increasingly take into consideration a multitude of stationary, mobile, and even embedded information technologies and their associated use contexts. In assembling such ubiquitous computing environments, multiple organizations with diverging interests and capabilities are involved. Indeed, heterogeneous component technologies are frequently associated with independent markets lacking a dominant actor knowledgeable about more than fragments of the combined capabilities present. A resulting lack of architectural knowledge poses a challenge to organizations attempting to assemble innovative computing environments spanning these boundaries. In this thesis, heterogeneous IT innovation processes are conceptualized as dependent on dispersed component technologies and associated competencies bound together by boundary-spanning architectural knowledge. This perspective is formalized as a research model assessed over a five-year action research project in the Swedish transport industry. The research project involved an industry network of independent technology vendors and user organizations experiencing a mobile-stationary divide in attempts to assemble ubiquitous computing environments. Seeking to understand the role and nature of architectural knowledge in heterogeneous IT innovation processes this thesis contributes implications for both research and strategy.

First, architectural knowledge in heterogeneous IT innovation is found to rely on technology capability awareness, use context sensitivity, and business model understanding. However, in order to be successfully enacted in practice, the emergence of boundary-spanning competence is crucial. It is imperative to collectively define mutual boundaries between components of an architecture with respect to technology capabilities, use contexts, and business models. Through this process, architectural knowledge emerges as actors gain an increased capability to appreciate the conditions present in other components. This creates a crucial foundation for boundary spanning innovation. However, such boundary definitions must reflect a viable common denominator. Any resulting formalized architecture should not pose an immediate threat to perceived core markets of any involved component IT base. The need for open boundary-spanning component capabilities and requirements of innovation leeway for individual firms within their core IT base pose a balancing challenge. This can be achieved by black-boxing disputed technology capabilities of the component IT bases, acknowledging the innovation prerogative of organizations within that particular component market.

Keywords: action research, architectural knowledge, heterogeneous IT innovation, ubiquitous computing environments,

Gothenburg Studies of Informatics, Report 40, October 2007
ISSN 1400-741X (print), ISSN 1651-8225 (online),ISBN 978-91-628-7319-6
Language: English
Pages: 192

PREFACE

This thesis is but an attempt at summarizing years of rewarding interactions and demanding work. It goes without saying that I have a lot of people to thank for their various and invaluable contributions. First of all I would like to thank Rikard Lindgren for providing the opportunity to begin this journey and his unyielding support as a mentor. For supportive and insightful comments I would also like to thank Ola Henfridsson. Throughout this time I have been fortunate enough to be a part of the Viktoria Institute, providing both financial and intellectual sustenance. Thank you all, for without you this thesis would never have been possible. The work upon which this thesis is built was funded by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

I have also been fortunate to spend a considerable amount of time with numerous people in all of the organizations that have taken part in this research. Any attempt to list them all would be a fruitless endeavor, but I would like to take this opportunity to express my gratitude. To all of you drivers, dispatchers, managers, and technicians, I am ever grateful for your time and patience. I would specifically like to mention the members of MSIgroup, some of whom have been there from the very beginning. Last, but most definitely not least, for enduring, thank you Anna.

Göteborg, October, 2007

Magnus Andersson

TABLE OF CONTENTS

1 INTRODUCTION

1.1 RESEARCH SCOPE

Traditionally, organizational IT innovation has been understood in terms of processes of introducing stationary information technology into a single organization. However, developments such as increasing levels of physical mobility and digital convergence have begun to challenge such conceptualizations of IT innovation. Indeed, organizations must now take into consideration an expanding ubiquity of both mobile and embedded computing components in their continuous efforts to improve efficiency and secure competitive advantage. Requiring specific knowledge pertaining to design and utilization, these heterogeneous technologies are often acquired externally rather than developed in-house. They are typically developed by equally heterogeneous types of organizations each with their own capabilities and limitations. This places specific constraints on the development of integrated organizational computing environments of stationary, mobile, and embedded technologies. It is this situation that forms the starting point of my research.

By taking an action oriented stance to research, this thesis includes practical as well as theoretical contributions. Subject to analytical generalization, the findings from my research would readily apply elsewhere. However, the empirical context has been of great importance to my work. I would therefore like to begin with introducing the Swedish road haulage industry and its use of information technologies as it were at the outset of my research endeavor. Found in this setting are two types of organizations of importance to this work: road transport organizations and vendors of IT components.

1.2 ROAD TRANSPORT

Road transport is a critical component of the global economy. Each day the European transport industry deals with 15 million courier-, express-, and parcel shipments, carrying a total of approximately 50 million tones of goods. Of all goods moved within the European Union, commercial vehicles transport 44 percent. With regard to inland freight transport, trucks move 74 percent. In 2002, the total volume of road transports undertaken by EU registered haulers was 1,347 billion tones-kilometers. While national transport accounted for the vast majority of the total road transport volume, international transport made up some 20 percent (Berg Insight 2006).

At first glance, the road transport firms[1] performing these jobs firms appear similar, the most obvious example being that trucks, drivers, and transport activities are at the core of the organization. However, the road transport industry is far from homogeneous in that core business activities, organizational structures, and size vary tremendously. Road haulage can be characterized as a diversified line of business, covering both local distribution of goods requiring loading and unloading several times each day and long distance transports where it can take days between loading and unloading. Accordingly, the nature of work ranges from rather static work in which transport activities can be planned ahead to time critical situations in which assignments have to be communicated from headquarters to the driver during the day. Although many work designations can be found, they can be characterized as either mobile (primarily the drivers), or stationary (for example dispatching, maintenance, and management).

While statistics indicate a trend towards fewer and larger companies, a majority of the Swedish fleet is still operated by small and medium sized companies. In 2005, 96 percent of the firms in the Swedish transport industry had less than 20 employees yet employed 43 percent of the total work force of the industry (SCB 2007). In fact, the entire European road transport industry is characterized by a high proportion of small and micro enterprises (Berg Insight 2006). Additionally, the Swedish road transport industry sector undergoes changes caused by the European Union open market. As an example, foreign transport firms have increased their share of transportations, which is a direct result of lower costs in nearby countries such as Denmark, Germany, Netherlands, and Poland. This cost disadvantage has rendered to minimal profitability margins for small and independent road haulage firms. For instance, in 2006 Danish trucks transported seven times more goods to and from Sweden than did Swedish trucks (SIKA 2007). In this situation contractors of haulers such as DHL and Schenker who do not own the fleets executing the transport assignments they manage have strengthened their market position. Like counterparts in Europe and North America, Swedish road haulage firms are implementing different types of information technology to improve their competitiveness.

Analogous to most industries, the size of transport organizations is a critical factor in that it determines the amount of resources for procuring and administrating information technology (Williams and Frolick 2001). Being small firms, Swedish road haulers rarely can afford to

[1] Throughout this thesis a number of terms have been used to denote these organizations such as “road transport organizations” or “road haulage organizations”. In the context of this thesis, they are all interchangeable.

develop a custom built system as to secure technical advantage. Rather, they are typically forced to consider the various off-the-shelf solutions available. The wide variety of business activities in road haulage firms makes this choice complicated. Such geographically dispersed IT support is complex in terms of the number of portable devices, embedded applications, databases, and systems involved. Additionally, organizational considerations such as a multiplicity of physically dispersed use contexts must be taken into consideration.

1.3TECHNOLOGY VENDORS

The second type of organization of importance in this research is that developing and supplying such technologies: the information technology vendors. In my research setting these form a diverse collective unified primarily by their capability to deliver industry specific information technology of various kinds to customer road transport organizations. Besides industry specific stationary information systems, continuous advances in mobile, embedded, and wireless technology such as global positioning systems (GPS), radio frequency identification (RFID), and embedded vehicle systems have enabled the development of a wide range of sophisticated applications supporting daily activities (Akinci et al., 2003; Angeles, 2005; Giannopoulos, 2004; Roy, 2001). Among other things, these endow the organization the capacity to track trucks and cargo or continuous flows of vehicle performance parameters such as fuel consumption and driver behavior, and wireless communication of data from some or all of these tools. The positions of individual trucks can be displayed on digital maps, offering dispatchers a quick overview of the geographic distribution of the mobile resources. Route calculation utilizing IT support done by the driver in the field or by the dispatcher is intended to minimize the cost of a transport assignment in terms of time and fuel expenditure. Underlying technologies are utilized by vendors to develop higher level information systems and services. Diversity follows both the main technologies employed and the services adapted to specific use contexts targeted by vendor organizations.

1.4 INITIAL PROBLEM SITUATION

When I started my research in the fall of 2002, the primary role or area of expertise of any given vendor organization was far from given. Though initially specialized, a vendor organization would not necessarily operate in any one single area of application, or use context. Rather, each of these vendor organizations would focus their offerings to varying degrees on embedded, mobile, or stationary information technology respectively. This frequently meant that while they mainly developed information technology and an associated knowledge, pertaining to either stationary or mobile or embedded technology, at the same time they pursued secondary development goals in any of the other areas. As perceived by transport organizations, the resulting situation constituted a major obstacle. More specifically, they believed that it complicated the process of both choosing and integrating the various technology components available to road transport organizations into a sufficiently coherent organizational computing environment.

1.5 Thesis structure

This thesis is structured as follows. First, in order to relate the concept of ubiquitous computing to this and similar industrial applications emerging, I will give an account of the concept, my specific utilization here, and theoretical questions raised by the IS community. Following this I will discuss how the resulting heterogeneity in innovation processes can be conceptualized in terms of extant literature on IT- and architectural innovation. This reasoning is formalized into a research model of architectural knowledge in heterogeneous IT innovation. In relation to this research model I present my research question. Next, my research method, context, data sources, and analysis are presented. After this, my research process is dealt with at some detail. The next section gives a brief account of the peer reviewed research papers that are part of this thesis and places them in the overall context of the research project. Finally, the findings of critical architectural knowledge dimensions in heterogeneous IT innovation processes are discussed and conclusions are drawn for both research and practice. Concluding the thesis are five individual research papers in their entirety.

2 UBIQUITOUS COMPUTING ENVIRONMENTS

2.1 HISTORY

Since the inception of the term, ubiquitous computing has been viewed as a concept challenging the stationary desktop-metaphor of design in computing practice (Weiser 1991). Instead of focusing on the stationary computing device, the personal desktop computer, people would interact with a multitude of interconnected devices. When Mark Weiser, manager of the Computer Science Lab at Xerox PARC, coined the term, he referred to a vision of computationally enhanced and interconnected buildings, furniture and other objects through which computation would ideally become seamlessly integrated into the activities of everyday life. Indeed, continuous miniaturization and advances in wireless communication has since made mobile computing an aspect of everyday life by providing information services at anytime and anywhere (Lyytinen and Yoo 2005).

However, ubiquitous computing is more than mobile phone services. Within this field of research there is a large number of different themes (Abowd and Mynatt 2000). Among others, researchers developing context aware prototypes have a very specific goal. By determining and capturing relevant data on users' immediate environment of concern, services are to be adapted to the context of use (Abowd and Mynatt 2000; Grudin 2001). For example, the mobile phone would automatically mute its ring tune if the surroundings allowed it to sense that it was in the theatre and that a play was well underway. Thus, by physically embedding and interconnecting computing into surroundings, clothing, or even people, proponents of this research agenda hope to provide ubiquitous yet unobtrusive computing. Applications and services are to become aware of their surroundings and act accordingly. To accomplish this, sensor networks embedded into the environment and various devices are to pass context information fragments to the context aware applications that interpret these signals using a set of rules. Aspects of importance to creating context awareness include the physical environment such as location or temperature, time, device and network characteristics and social context (Roussos 2006b). Essentially this development indicates a move from the mobile computing vision of "anytime anywhere" to "right here right now" as a paradigm for future service development in the sense that services would no longer look or behave the same regardless of place or time (Dourish 2001). While progress is being made in experimental application prototyping, ubiquitous computing research has primarily focused on the individual boundlessly immersed in computing (Abowd and Mynatt 2000) largely passing over organizational issues of implementation.

2.2 Industry

Ubiquitous computing has now gained ground in the organizational world as organizations are beginning to develop ubiquitous computing environments (UCE) to innovate their business proposition and increase customer value. As organizations explore the potential of interconnected stationary, mobile, and embedded computing components, new questions surface. Indeed, such developments can be traced in the appearance of dedicated IS conferences (e.g. Sørensen and Yoo 2005) and special issues of premier IS journals (e.g. Topi 2005; Yoo and Lyytinen 2005) fuelling the academic debate surrounding ubiquitous computing.

A UCE can be seen as a number of interwoven information technology components of different character. In this context, three fundamental realms can be discerned that deal with stationary, mobile, and embedded information technologies respectively. In this sense, stationary enterprise systems are being augmented by information processing capabilities offered by mobile applications and devices and computing power embedded into physical surroundings and objects. Technology-wise, a UCE thus consists of an assemblage of heterogeneous base IT components (e.g., stationary, mobile, and embedded) that are interconnected through communication technologies (e.g., cellular, PAN, and LAN) and application interfaces (e.g., specific XML-schemas). A UCE promises to function as an infrastructure with potential to solve needs for information services that span functions within and across organizational borders within an industry. The distinction between the stationary, mobile, and embedded base technologies is an analytical one and the actual configuration of technologies and stakeholders is dependent on the industry in which the UCE is intended to function.

Among the main technologies that herald this development are automatic identification of physical objects via radio frequency tags (RFID), location sensing via Global Positioning System (GPS), and various types of sensors arranged into networks. Many UCE components like these are already being used in industries, for example to optimize supply chains (Roussos 2006a). In UCE development, multiple organizations will become involved (Fleisch and Tellkamp 2006). In my research setting, there are multiple suppliers of component technologies. First, there are vendors focusing on dedicated office transport management systems. Second, there are vendors focusing on communication systems and devices to support mobile workers. Third, there are vendors of information technologies embedded into non-dedicated physical objects. Commonly, this last type of vendor also supplies the object into which the technology is embedded (e.g. Jonsson et al. forthcoming). An example of this is a truck manufacturer who supplies sensor networks and applications physically embedded into the truck. In this sense, and concurring with extant information infrastructure literature (Star and Ruhleder 1996; Hanseth and Monteiro 1997), an UCE is not developed from scratch. It is rather modified gradually in response to multiple actors' (e.g., various system vendors and user organizations) concerns and actions. Comparatively newer components are being interwoven with older and the resulting computing environments grow ever more capable to provide organizations with dynamic data.

Given the complexity following interaction between independent and heterogeneous actors and technologies in a UCE context, an organization seldom possesses enough knowledge to innovate singlehandedly. Rather, such knowledge is distributed among separate communities of technology vendors of different kinds and user organizations. In this sense, innovating within the realm of UCE does not sit well with the received logic of IS innovation, traditionally more focused on adoption of information systems in the single firm based perspective. Indeed, new developments in IT such as those described here seem to promote new forms of inter-organizational innovation (Van de Ven 2005; Yoo and Lyytinen 2005). Considering the heterogeneous nature of the transport industry IT setting as described earlier, it is a promising setting for studying such complex interactions.

3 HETEROGENEOUS IT INNOVATION

3.1 IT INNOVATION

Organizational innovation broadly refers to new applications of knowledge, methods, and technologies that make an organization more competitive (see e.g., Becker and Whisler 1967; Daft 1978; Dewar and Dutton 1986; Rogers 1995; Sheremata 2004). While early work applied a restrictive definition of innovation by limiting newness to the first user within an industry (Becker and Whisler 1967), over time a more inclusive view has evolved highlighting the perception of novelty among individuals, organizations, and communities (Daft 1978). This perspective is echoed in the existing IT innovation literature. Notably, it primarily focuses on post-adoption analysis of IT innovation (see e.g., Swanson 1994; Lyytinen and Rose 2003). Consequently, IS research has focused on the uptake of existing innovations in organizations. Methods and strategies have tried to specify the nature of processes of introducing IT innovations successfully into organizations. However, this perspective takes for granted the innovation per se and do not shed light on what causes such innovations to be, or indeed not to be, in the first place. This perspective is currently being supplemented by a broader perspective on IT innovation processes.

Attempting to broaden the scope and understand the impact of innovation occurring outside organization boundaries to explain subsequent in-firm changes, Lyytinen and Rose (2003) contributed the notion of IT base. This concept serves to highlight the purely technological character and potential of IT innovations. It consists of three dimensions: base technology innovation, base development capability innovation, and base service capability innovation. First, the base technology innovation concerns technological properties including issues such as "functionality, speed, reliability, architectural principles, and other features" (Lyytinen and Rose 2003, p. 562). In this sense it subscribes to the analysis of comparative studies of quantifiable features found in many other product oriented innovation studies (see e.g. Christensen 1997). Second, base development capability refers to the information systems development process changes enabled by the IT base innovation. This refers to a range of subsequent innovations made possible by the given base IT innovation. Third, base service capability refers to actual IT service changes facilitated by the base IT innovation. Again, this intends to convey a number of potential innovations that build on the source innovation.

Lyytinen and Rose (2003) show how innovation in the IT base is a necessary but not in itself sufficient condition for subsequent system development and service innovation. While the notion of IT base has served to nuance the conceptualization of IT innovation, it is slightly insufficient when discussing ubiquitous computing innovation. Primarily, it does not advance understanding of the innovation processes required to align dispersed technologies and their associated communities of developers and users.

3.2 Ubiquitous Computing Innovation

What characterizes UCE innovation is its inherent heterogeneity of base technologies. It serves little purpose to discuss of such innovation analytically as consisting of an abstract IT base encompassing vastly different technologies developed and applied in equally different contexts. Indeed, innovation can be characterized as the carrying out of new combinations of preexisting components (Schumpeter 1934). In perceiving of embedded, mobile, and stationary computing as high level components, the process of innovating UCE becomes the combinations of not only different base technologies, but also the heterogeneous communities that design and use them. To avoid glossing over this complexity, the nature of such intersections of multiple IT bases must be addressed.

Yet another distinguishing feature of these components is that one is not necessarily dependent on another to provide end-user services. For instance, a stationary office system need not be integrated with either mobile or embedded components to deliver services to the user organization. Similarly, an embedded vehicle diagnostics suite need not be integrated with stationary or mobile components to deliver value to a user. This lack of obvious coherence and hierarchy complicates processes of innovation in that there is no given authority deciding on which are appropriate combinations to try. Rather, each component follows its own innovation trajectory.

Finally, as a consequence, these component IT bases are not designed for each other. Indeed, they are not even designed to fit the same types of use context. In otherwise similar settings, technologies as components are frequently dependent on other technologies to deliver end user services (see e.g., Yoo et al. 2005). It is the combination of components that deliver value as perceived by users; they provide little value by themselves. Even though partaking firms can be said to have clearly divergent views, in such scenarios there is frequently a locus of innovation in the form of an entrepreneur or focal firm upon which the network depend (see e.g. Boland et al. 2007). In a potential UCE setting, self-contained networks including technology vendors and users often exist side by side in organizations, their interconnection vague or undetermined altogether. The presence of base technologies required for UCE innovation is therefore a necessary but not sufficient factor in UCE innovation.

There are, at least, two challenges of UCE innovation that merits revisiting the existing IT innovation literature: first the development of architectural knowledge spanning external (to the focal firm) IT bases, and second, the specific constraints involved in doing so. First, UCE innovation involves multiple component IT bases. These are heterogeneous not only in terms of technological capability but also in terms of the specific knowledge required to utilize them to innovate services successfully in a given context. This means that orchestrating UCE innovation within an industry requires the bridging of existing but up to that time largely unrelated technologies and communities, both in design and use. As each member from each organization involved needs to know his own job and thus his own component specific context, but do not need to know anyone else’s (Nelson and Winter 1982 p. 105), this bridging will most likely be challenging. More specifically, as this bridging affects the validity of current knowledge of feasible relations between components held by all involved organizations, it displays essential characteristics of architectural innovations (Henderson and Clark 1990 p. 10). Such innovations change the way in which components are "…linked together, while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched" (Henderson and Clark 1990, p.10). Again, the various components in the UCE case could be considered complex end products in their own right. In this regard, the development of new architectural knowledge is an essential element in UCE innovation that we currently know little about.

Second, in developing such architectural knowledge, multiple firms associated with different primary IT bases are involved. The outcome of such processes will eventually define their role in the emerging UCE in relation to others with respect to competence and market. These organizations are likely to experience a lack of knowledge about managing this kind of collective innovation process. A fruitful way of envisioning this experience is the cyclical model of industry-wide innovation depicted in Anderson and Tushman (1990). Such innovation involves a period of intense struggle among a range of possible configurations before any single architecture can be considered dominant in an industry. In such times, a host of heterogeneous stakeholders attempt to define and impose on the industry an architecture that is based on their own specific perception of the capabilities of the constituent components. In most innovation processes, the market prize of having defined a dominant architecture is well worth the initial risks of pursuing such a strategy (Teece 1986). However, in view of the independent character of the high level components of a UCE, it is by no means certain how such innovation processes could be controlled as it necessarily spans areas outside the any single organization's immediate IT base and associated knowledge.

3.3 ARCHITECTURAL KNOWLEDGE

As suggested above, the architectural innovation theory makes a distinction between a product as a system and as a set of components (Henderson and Clark 1990). First, a product consists of a set of components, each implementing a distinct portion of the product and performing a well-defined function. The implementation of this well-defined function embodies a core design concept. While the functional basis of this definition suggests that a specific component might rely on alternative core design concepts, a dominant core design concept relies on a distinguishable body of knowledge, i.e., *component knowledge*, which have typically been acquired, applied, and refined over a long period of time**.** In UCE settings, such component knowledge (IT base knowledge) resides with the particular IT base as well as the industry relationships and markets developed around this base. Second, a product relies on an idea of the integration and linkages between each of these components. As suggested by Henderson and Clark (1990), this idea relies on a specific kind of knowledge, i.e., *architectural knowledge*. In this thesis, architectural knowledge is referred to as knowledge developed and enacted in processes of aligning heterogeneous business and technical elements in an innovation process.

Henderson and Clark's (1990) model assumes an evolutionary perspective on innovation. In the early stages of an innovation’s existence, there exists a lot of experimentation and improvisation. Multiple incarnations of architectural innovation initially exist side by side in a struggle for dominance. However, over time, gradually stabilizing architectures are reflected in the internal communication channels and associated filters running through an organization (cf. Daft and Weick 1984). This makes the organization very well adapted to competitively tackle evolutionary developments within the current architectural scope. The consolidation of architectural knowledge serves to fine tune the organization’s internal innovation activities. Since the crossing of organizational boundary can add to the costs of information transfer, firms seeking to improve the transfer of ‘sticky’ information will seek to align their organizational boundaries – and their specializations – with the partitioning dictated by the types of innovation-related problem-solving tasks that are perceived as most important to them (von Hippel 1998). Indeed, to some degree organizational layouts could be viewed as mimicking the arrangement of components forming the complete architecture of an actual finished product.

Though the concept of architectural innovation has primarily focused on firm based product development, it has recently been used in rather more complex infrastructural and multi-organizational settings (Soh and Roberts 2003). In the context of UCEs, this may be even more complex as the respective components often be regarded as finished products or systems in their own right, not as mere fraction of a product. As such, isolated IT bases and associated vendors and markets already exist, while their actual interlinking into a UCE necessitates boundary spanning development of architectural knowledge. Such knowledge development over boundaries can be highly problematic as the individual firm’s learning with respect to new outside information is largely a function of the firms prior related knowledge (Cohen and Levinthal 1990). Bound by previous experiences gained from one IT base, such dependencies are highly problematic in a UCE context in that it requires knowledge of several IT bases. None the less, to enable the formation of architectural knowledge spanning multiple component IT bases, novel communication channels and filters are necessary.

As emphasized in information infrastructure literature, the development of complex IT systems is not done from scratch (e.g. Grindley 1995; Hanseth and Monteiro 1997). An installed base of technology and existing markets constrain the range of possible configurations. As an example, the multiple IT bases of a UCE created in a business setting is seldom new on their own. However, their specific inter-linking may result in a new application of IT that fundamentally changes the value of previously held architectural knowledge in an industry. Such general inability of incumbents to cope with radical changes has been well documented (e.g. Christensen 1997). This can partly be explained by the communication filters (Henderson and Clark 1990) developed throughout the organization. These tend to stabilize around well known concepts and stable innovation trajectories. However, in seeking such stability, potential innovations may be overlooked. Indeed, by assessing the performance of new architecture using metrics used for that used by established market applications, it may mistakenly be dismissed as irrelevant or inferior.

In hybrid industries composed of widely heterogeneous actors such knowledge is increasingly difficult to master. Encompassing radically diverse computing capabilities, the case of UCE is a good example of such developments. The specific problem in such settings is that the combination of infrastructure components required for service level innovation are often not under the control of one single player or indeed type of players. Rather, the innovation potential of the environment is essentially distributed across competing organizations as well as IT bases, each having an independent market. As a consequence, the complexity of managing complementary resources (Teece 1986) in such environments increases.

There is growing evidence that inter organizational architectural knowledge is becoming increasingly important in information systems development. This trend is not only reflected in recent calls for research on innovative ways of integrating various computing components (March et al. 2000; Lyytinen and Yoo 2002), but also in studies of the role of standards in assembling and integrating heterogeneous computing components for innovative business value (Yoo et al. 2005). The model of architectural innovation originally addressed firm based innovation activities. However, as Chiasson and Davidson (2005) note, the concept industry is relevant when studying problems to which individual firms seek solutions in collaboration with competitors within the same business setting. Examples of such collaboration can be the formation of industry associations to promote common interests, to develop shared infrastructure, and to exchange information. Developing industrial architectural knowledge is typically not a firm-bounded endeavor. Supporting inter-firm mobility of information for improved business operations, such knowledge is characterized by its boundary-spanning quality (Van de Ven 2005).

Successful innovation and diffusion of services in these settings are collective achievements and firms need to deploy strategies that enable them to mobilize broad socio-technical networks that include technological, institutional, political and financial resources. Standards often mediate different interests and motivations among industry actors (Yoo et al. 2005). Indeed, evidence from standard-making in various industries show that collaboration often scale up to an industry level when heterogeneous technologies and organizations are attempted to be weaved into everyday work practices (Hanseth and Monteiro 1997; Markus et al. 2006).

3.4 A RESEARCH MODEL OF HETEROGENEOUS IT INNOVATION

In the preceding sections, perspectives on the nature of architectural knowledge and IT base pertaining to heterogeneous UCE innovation processes have been developed. The research model depicted in figure 1 integrates these core concepts and important linkages for understanding the role of architectural knowledge in IT innovation where heterogeneous IT bases are involved. The understanding of these concepts and their relations has been fundamental to the research on which thesis builds. Each component represents an independent market built on a specific IT base. Over time, firms operating in a particular market have developed a discernible body of knowledge that has been acquired, applied, and refined over time. I refer to this stock of knowledge as component knowledge.

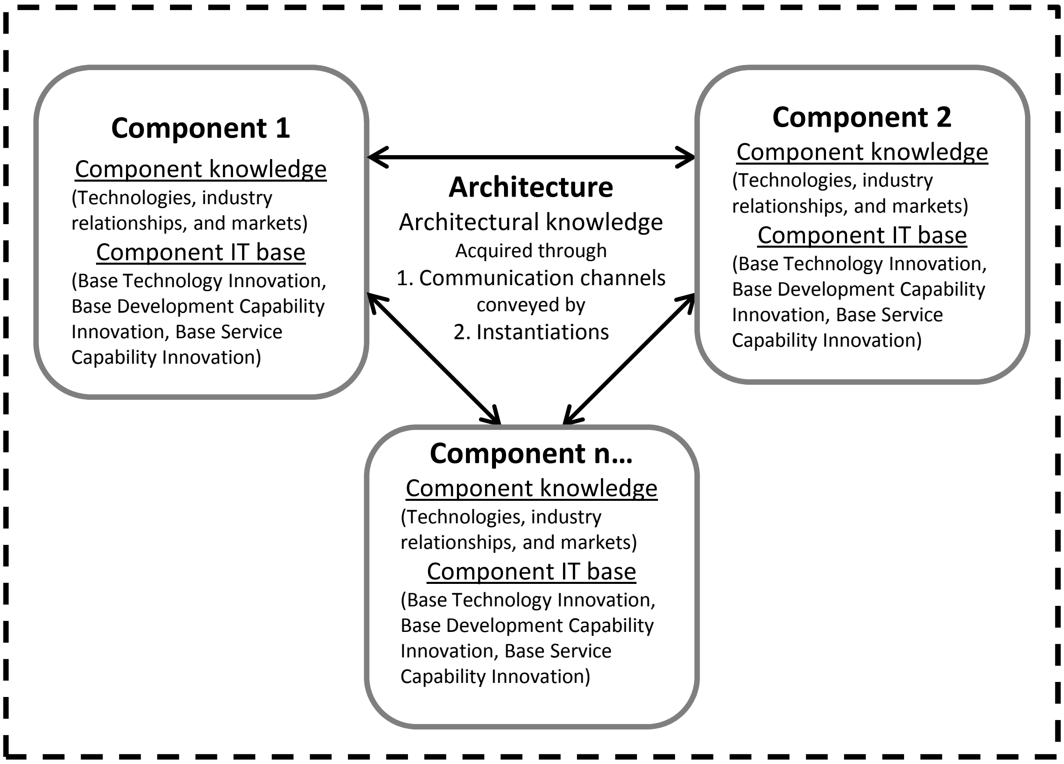

Figure 1: A research model of Heterogeneous IT Innovation

In heterogeneous IT innovation, two or more components are interwoven as a result of a collective activity of firms operating in different markets. They create an architecture that links the independent components in ways that serve the interests of the clients of an industry. In order to do this, architectural knowledge needs to be developed. This model builds on the assumption that such architectural knowledge is acquired through collective activities. First, the development of communication channels and filters between firms, and second, the instantiation of architectural knowledge through IT bases boundary-spanning standards.

4 Research Question and Objective

As suggested above, a single organization rarely boasts the necessary knowledge or capacity to innovate information services through diverse component IT bases such as stationary, mobile, and embedded concurrently. Recent innovation literature has labeled the notion of open innovation (Chesbrough 2003) to frame the necessity of collaboration between innovating organizations. In such innovation settings, it is vital to understand how actors with diverging strategic incentives and capabilities could cooperate to develop complex environments (Van de Ven 2005). This shift in scope from the organization to the industry necessitates the study of complex interactions in infrastructural IT innovation processes focusing on the spanning of boundaries of partaking organizations and communities.

There are few examples of IS IT innovation research targeting similar issues, but one merits mentioning. Utilizing the development of national mobile infrastructure as an example, Yoo et al. (2005) conceptualize multi-organizational innovation processes as consisting of three cycles; an innovation cycle affecting the innovation system, a diffusion cycle affecting the marketplace, and a regulatory cycle affecting the regulatory regime of any given complex socio-technical IT system innovation. Through the innovation cycle, "…new features are projected into the technological world and become established as candidates for future mobile services, enabling actors to relate to other actors and artifacts in new ways" (Yoo et al. 2005 p.). Such innovation cycles are typically organized through generations of standards. In sum, Yoo et al. (2005) outline a detailed analysis of innovation processes that involve alignment and linking of heterogeneous actors. As indicated by (Lyytinen and Rose 2003) and shown by Yoo et al. (2005) actors in the base technology innovation system compete by innovating infrastructural technologies that subsequently enable a different set of actors in the marketplace to innovate services building on the new base capabilities.

However, heterogeneous IT innovation is essentially a processes a process of assembling highly independent stationary, mobile, and embedded components. Such relations are not characterized by hierarchical value chains orchestrated by a single type of organization from the top down. Rather, they are characterized by fragmentation and unclear relations and vague boundaries. Therefore, in developing a UCE, there is no obvious locus of innovation guiding the process. This fragmentation is likely to influence the development of crucial boundary-spanning architectural knowledge. These pertinent issues are important components of my overarching research question:

How can architectural knowledge be developed in industries characterized by heterogeneous IT bases?

Building on Henderson and Clark's (1990) theory of architectural innovation and Lyytinen and Rose's (2003) notion of IT bases, this thesis develops a theoretical perspective that helps to explain how architectural knowledge spanning heterogeneous technologies and associated communities and markets can be collectively developed within an industry. This perspective emerged throughout the 60-month duration of a canonical action research study (Susman and Evered 1978) within the setting of the Swedish road haulage industry.

5 Research Method

This section contains a description of my research method, the context in which it was employed and the unfolding process of doing so. In the summary account of the research process, I have included references explicating the role of individual research papers of this thesis for my work.

5.1 Action research

Most research methods employed in IS research are used to study organizational phenomena but do not attempt to incur change. In contrast, action research has the joint purposes of planning and promoting practical change and generating knowledge resulting from these efforts. Action research has specifically been introduced to solve current practical problems while furthering theoretical insights (Baskerville and Wood-Harper 1996; Mathiassen 2002b). Using a real world problem to advance theory, the method is clinical in character (Baskerville and Wood-Harper 1996) and has been referred to as a means of ensuring practical relevance of IS research (Baskerville and Myers 2004).

Furthermore, by joining the goals of advancing theory and improving practice (McKay and Marshall 2001), action research requires intense collaboration between researchers and clients (Mathiassen 2002a). While action researchers bring knowledge of action research as well as of general theories, clients bring situated knowledge. A key feature of this research approach is a willingness to share and thus learn, resulting in enhanced competencies of all concerned (Hult and Lennung 1980). While these characteristics can be seen as generally applicable to the method, there is no consensus on the ideal practice and action research has been characterized as diverse (Baskerville and Wood-Harper 1998). However, an action research process is characterized by a cyclical approach involving a number of steps (Baskerville and Myers 2004). In this thesis the five-stage model presented by Susman and Evered (1978) is used. In IS literature, this model has also been referred to as canonical action research (CAR) (Baskerville and Wood-Harper 1998).

The cycle phases proposed by Susman and Evered are diagnose, action planning, action taking, evaluation, and specify learning. Diagnosing a perceived problem situation, researchers and clients collectively build a preliminary understanding of the causes of a non-desirable situation. Theoretically guided action to alleviate the problem situation is subsequently planned and executed. The outcome is then evaluated and the learning from the cycle of action research is specified. Depending on the positive or negative outcome as perceived by researchers and clients of the research endeavor, the end of the cycle may or may not spawn yet another in which the hypotheses are modified to take into account the lessons learned so far. In this research, a real world problematic situation is related to a theoretical understanding of the evolving implementation and development of UCE by actively intervening to promote and study the effects of theoretically guided changes in practice.

5.2 RESEARCH CONTEXT

The empirical context of this thesis is the Swedish road transport industry. A UCE in the road transport industry consists of embedded vehicle systems, communication systems, fleet management systems, and traditional office systems. Table 1 lists information technologies typical for the road transport industry. Technologies from mobile, stationary as well as embedded IT bases effectively involve all daily functions of a transport organization. Throughout this industry, UCEs are partly realized by a multitude of systems and associated vendors. This made it an ideal setting in which to study the evolving architectural knowledge surrounding UCEs.

Component IT base	*Functionality*	*End-users*
Stationary IT base: • Desktop systems • E-business solutions • Office automation technology	This type of IT support is aimed at improving transport management efficiency: • Event-triggered alerts and geo-fencing • Geo-positioning • Navigation and route optimization • Order management • Route optimization software • Vehicle, cargo, and goods monitoring and tracking	• Managers • Dispatchers
Mobile IT base: • Nomadic devices integrated with vehicle electronics in cockpit • Vehicle-mounted communication terminals	This type of IT support is aimed at improving the efficiency of mobile workers: • Communication between stationary personnel and mobile workers • Information about mobile workers' positions • Text messaging	• Drivers
Embedded IT base: • Active ignition sensing software • Barcode scanners • CAN-bus • Electronic trip recording software • GPS receiver • RFID technology	This class of IT support is aimed at improving vehicle utilization and driver productivity: • Breaking and shifting behavior analysis • Driving and stopping times tracking • Driver working time analysis • Fuel consumption and trip distances monitoring • Maintenance planning • Navigation software	• Managers • Drivers • Dispatchers

Table 1: IT support in the transport industry

The research covered in this thesis spans a 60-month effort. Conducted between September 2002 and August 2007, the "Value-Creating IT for Road Haulage Firms" project[2] was a collaborative effort between the Viktoria Institute and a large transport industry network. The industry network consisted technology vendors (Hogia, IBS, Locus Scandinavia, MobiOne, Mobistics, Scania, Transics, Transware, Vehco, and Volvo Trucks), road transport firms (AA, SÅAB), and a consultative organization jointly owned by 16 Swedish transport organizations (TRB).

---

[2] The project was funded by VINNOVA and the participating organizations. VINNOVA is the Swedish Agency for Innovation Systems, which integrates research and development in technology, transport and working life. VINNOVA's mission is to promote sustainable growth by financing R&D and developing effective innovation systems. For more information, go to http://www.vinnova.se/.

Representing these main system vendors and a sizeable part of the combined fleets in the Swedish transport industry, the industry network brought considerable transport system development and use experience to the project. The action researchers brought theoretical knowledge about general IT innovation theories and ubiquitous computing. The project was initiated by the researchers, but once the Client-Researcher Agreement (Davison et al. 2004) was signed the authority of the project was assigned to a team consisting of practitioners and researchers. This team was responsible for the formulation and follow up of activities and the communication with the organizations represented.

5.3 Data collection and analysis

As action research necessarily follows developments in client systems, data gathering is frequently an arduous task. A multitude of data gathering methods were used throughout the project. The challenge posed by not knowing in advance what data might be necessary in a research endeavor of this character (Mathiassen 2002b) has been addressed by a focused data collecting effort including extensive recordings of both interviews and project meetings throughout the project.

I attended most of the 20 project meetings held in the five-year project. Since many views relevant to the development of architectural knowledge were revealed at these occasions, most of the meetings, frequently over four hours long, were tape-recorded and transcribed for later retrieval during the data analysis. In total, 80 formal interviews were performed, recorded, and transcribed at various stages of the project. Respondents included technology vendors, drivers, dispatchers and transport organization managers. Lasting between one and three hours, they covered different themes relevant to IT development and use in the transport setting.

This material has been supplemented with observational studies and news articles in trade press relevant to the client system and the actions taken. Reviews of product documentation helped form an initial understanding on the technologies involved. Access to documentation on proprietary interfaces was crucial to the formulation of the final parts of my research. Additionally, during the latter part of the project, extensive prototyping was employed as a means of alleviating the problem situation. By actively leading this intervention, I gained a thorough knowledge of the technologies and development methods employed in the industry through numerous work meetings with developers from the various organizations. Finally, notes from informal conversations and presentations have been taken throughout the project.

Source	*Amount/content*
Project meetings	20
Interviews	80
Workshops	5
Strategy documents	Describing vendor business
Technical documents	Review of various product- and technical documentation
Work meetings	38
Presentations	9

Table 2: Overview of data sources

As recognized in literature on interpretive research, the interpretations of the researcher are based on interpretations of the respondent (Van Maanen 1979). Since interpretations are implied in any verbal communication, my interpretations could have influenced respondents' interpretations. Referred to as double hermeneutics (Giddens 1976), I have continually set out to reduce such effects by consciously adopting an open-minded manner as to avoid any over-directing. In this vein, all formal interviews have been of an open semi-structured character and have provided ample opportunity for the respondent to divulge matters outside the rigidities of a questionnaire. Though such risks cannot be fully excluded in any study, I found complementing data sources including written documentation, technology and system demonstrations, and project meetings helpful in the sense that they allowed triangulating results from formal interviews. For instance, the public statements in project meeting settings were useful for comparing statements with those uttered in interviews.

In terms of data analysis, the empirical categories were generated over time in working with this material in an iterative fashion. In line with the hermeneutic circle (Klein and Myers 1999), initial conceptions based on literature reviews and needs stipulated by the collaborative project planning, initial semi-structured interview protocols and a set of complementary data sources were produced. With an increased understanding of the setting in the course of collecting data from the client system by engaging with it to actively promote change, these conceptions were refined to better reflect the work practices and knowledge existing and emerging with the use of the studied technologies. Over numerous such cycles of deepened insight, my analysis was driven towards a progressively more detailed understanding of the role and nature of architectural knowledge in processes unfolding in the client-system. Notes on specific methods of analysis used throughout my research progress are included in the individual research papers.

5.4 RESEARCH PROCESS

The insights of this thesis are essentially an interpretation based on a cumulative experience spanning multiple years. Any account of such complexity necessitates a condensed format. Nonetheless, by utilizing the utilized five phase methodology as suggested by CAR as a structure, this account will illuminate the central events of my research and the emergent understanding of architectural knowledge. In doing so, I will also state the role of each of the five research papers in this thesis. More than isolated contributions, they account for the developments of my theoretical understanding and conceptualization of the empirical problem situation throughout my research.

The following describes two full cycles from diagnosis to evaluation. The character of these two cycles differs as the actions taken in the second builds on the lessons learned from evaluating those taken in the first. In the first cycle, action was taken to create communication channels where there were none. This action aimed to promote the emergence of architectural knowledge in the newly formed industry network. This first engagement provided me with an understanding of the nature of architectural knowledge grounded in the observed actions and inactions of actors. It did not, however, alleviate the problem situation in the industry. The second provided an application of the newly gained understanding of architectural knowledge to alleviate the experienced problem situation. This second action was design oriented. The design process that ensued was driven by the goal to instantiate the knowledge from the first cycle into a boundary object, thereby stimulating the development of boundary-spanning architectural knowledge. This boundary object was a standardized application interface.

5.4.1 FIRST ACTION RESEARCH CYCLE

To get an initial industry understanding of the empirical domain, together with research colleagues I visited the annual trade fair where some early observations were made. Importantly, rather than portraying their offerings in terms of customer value, technology vendors tended to highlight the technological excellence relative to competing vendors. As a result of the problematic situation, transport organizations tried to develop and implement their own solutions. In an attempt to identify the core competence of vendors, I reviewed available systems. Basically, there were three camps which gradually became referred to as the stationary, mobile, and embedded. These denominations highlighted the different IT bases and associated innovation trajectories that vendor solutions could be traced to. Given the relatively low IT competence among road haulage firms, the technological jargon of vendors did not facilitate fit between systems offered and problems perceived. Further contacts with industry actors were taken buy my research group. I participated in the undertaking of an interview study of road haulage firms' experiences of IT use. My experiences of that study can be found in the first paper of this thesis. Most importantly, this study helped clarify that the heterogeneity of IT bases was not only a matter of jargon but a real-world problem manifested in vendors' inability to understand the whole problem situation when implementing their solutions. User organizations were not satisfied with the competence of any single vendor to cater for all of these types of technology. Indeed, they considered most vendors as more or less confined within their own technological paradigm. Though calling for comprehensive solutions binding different IT components together, the industry at this stage was by and large characterized by fragmentation.

These lessons learned were subsequently fed back to technology vendors and transport organizations at a combined seminar and workshop hosted by the Viktoria research institute. The realization that this was the first time that these actors met to discuss industry concerns in a collaborative session was somewhat of a surprise. The workshop was indicated that better communication channels were needed to facilitate the development of comprehensive architectures needed in practice. This diagnosing phase resulted in the conceptualization of a reason to transport organizations' perceived fragmentation: knowledge sharing between heterogeneous technology vendors was non-existent. This insight together with a review of innovation literature led to the formulation of the overall working hypothesis: *the development of communication channels and filters between firms, belonging to different component IT bases, is critical for developing architectural knowledge in UCE settings.*

Given the newly formed hypothesis, action was undertaken to establish the communication channels hypothesized critical to stimulate architectural knowledge within the industry. The intention was to establish links over the boundaries of predominantly stationary, mobile, or embedded technology oriented organizations.

Inspired by the early workshop, a formal network of system vendors and road-haulage firms was formed with the intention to build a foundation for developing architectural knowledge. To secure commitment and clarify roles and responsibilities, the group was formalized in a researcher-client agreement (Davison et al. 2004). A governmental funding agency (VINNOVA) generated resources for creating network effects. Following this formalization of the industry group, five additional system vendors were aligned to the network. Indeed, the expanded network represented most of the main vendors operating in the Swedish transport industry at the time.

After forming the industry network, the next step was to assess the working hypothesis that communication channels and filters are necessary for the development of architectural knowledge in these settings. The AR team, consisting of researchers and representatives from the partaking organizations, decided on an evaluation strategy to meet this end.

Knowledge was to be tapped from ongoing integration projects. This would provide for two important contributions. First, the nature of architectural knowledge would be identified and specified. Second, traces of boundary-spanning architectural knowledge developed on the inter-firm level would be identified. The empirical data was supplied through seven integration cases feeding back experiences pertaining to the nature and development of architectural knowledge. In practice, members of the industry network offered me access to their most advanced cases of technology integration. Throughout the evaluation phase, an understanding of dimensions of architectural knowledge gradually surfaced. First, a critical issue was whether any single technology vendor would have the capacity to cater for a complete architecture including heterogeneous technologies. Even though there were actors who took on this single vendor role to meet transport organizations' expectations, most vendors studied realized their inability to handle IT components outside their core competence.

Second, during evaluation, a lack of sensitivity to user contexts in general and to such contexts relating to other components in particular was identified. For instance, in one of the cases studied, utilizing GPS technology, a vendor of mobile technology had implemented a system for optimizing mobile resource allocation at a transport organization. The CEO pointed out that dispatchers would no longer have to rely on extensive verbal negotiations with drivers to transfer information from the mobile context to their stationary. However, it soon turned out that there was more to the mobile context than positioning. Built into the new system, drivers had the option to decline any given assignment sent from the dispatcher. In doing so, the introduction of the mobile system unearthed a complex negotiation process between drivers and dispatchers. The perceived efficiency gains of the system in danger, dispatchers wanted to enforce their organizing logic on the mobile-stationary integration by depriving the drivers of the opportunity to negotiate. The emphasis on the stationary context was also evident with the transport planning system vendor. Even though the mobile system acquiring the context data was integrated with the stationary system, the utilization of embedded technology was essentially subject to the prior understanding of work practice embedded into the design of the stationary system. The integration was meant to replace much of the ongoing negotiation between dispatchers and drivers. As highlighted in the case, this clashed with the current work practice of dispatchers.

A third dimension of architectural knowledge identified was what became referred to as business model understanding. The cases indicated that there were situations in which clashing views on viable business models caused problems. It was clear that actors (both vendors of technology and transport organizations) were uncertain how to develop business models for data produced by embedded technology. It seemed particularly troublesome in situations where truck manufacturers were involved in the integration of heterogeneous technologies. These events indicated the special characteristics of boundary-spanning practices in multi-contextual environments. The third paper of this thesis contains an account of this perspective. Detailed reports on these studies are included in papers two and three, and (to some degree) five of this thesis. Paper two deals with intended and unintended consequences following enactment of UCE as present in transport organizations. Paper three expands the scope by tracing some of the uncovered challenges to the practice of heterogeneous vendor organizations. The concluding paper conceptualizes this understanding of the problematic attempts at enacting heterogeneous technologies into specific dimensions of architectural knowledge.

Three dimensions of architectural knowledge in heterogeneous IT innovation were identified: technology capability awareness, user context sensitivity, and business model understanding. However, it was also clear that few traces of architectural knowledge were recorded in practice. An inability of involved actors to collaborate was a contributing factor. The AR team partially traced such problems to the extensive reliance on proprietary application interfaces. Published by stationary vendors, these interfaces were to be utilized by their mobile and embedded counterparts for assembling the customer organizations computing environment. Indeed, mobile and embedded vendors had to adapt to be able to enter the market. Importantly, while these interfaces specified the capabilities of stationary systems, there were little or no dedicated support for mobile and, particularly, embedded technology capabilities present. In fact, these artifacts perpetuated the mobile-stationary divide that effectively separated relevant actors. Though the problems within the industry network persisted, the main assumption was still valid. Evidently, the process of improving architectural knowledge needed active input from all identified parties, vendors from all relevant IT bases as well as user organizations. Unfortunately, the utilization of proprietary interfaces constrained interaction in integration projects.

Action Research Cycle 1 (September 2002 to June 2004)

Research collaborators:

Initial Technology Vendors: Viktoria Institute, Hogia, NL Partner, Scania, Vehco, and Volvo.
User Organizations: AA, SÅAB

Data sources:

Project meetings	4
Work meetings	2
Interviews	59
Workshops	2
Technical documents	Product documentation, demonstrations
Observations	30 hours

Phase 1. Diagnosing

The mobile-stationary divide as a key problem with existing attempts to successful IT use (see Andersson and Lindgren 2005) was identified. Lack of communication between vendors appeared to be an important factor. The following working hypothesis was formulated: *the development of communication channels and filters between firms, belonging to different component IT bases, is critical for developing architectural knowledge in UCE settings.*

Phase 2. Action planning

In collaboration with a small number of representatives of the participating organizations, the establishment of a network of system vendors and road haulage companies that would facilitate knowledge sharing was planned.

Phase 3. Action taking

In CAR terms, a client-system infrastructure for knowledge sharing was established. This was formalized as a Researcher-Client Agreement (Davison et al 2004). Additional system vendors (IBS, MobiOne, Mobistics, Transics, and Transware) and user organizations (AA and SÅAB) were aligned to the network.

Phase 4. Evaluation

7 user site investigations were conducted at road haulage firms and vendors as to evaluate knowledge sharing-in-practice.

Phase 5. Specifying Learning

The working hypothesis was not supported. Despite improvement of architectural knowledge, the problem situation was not substantially alleviated. In particular, existing proprietary interfaces were identified as a hindrance to the enactment of boundary-spanning architectural knowledge. These new insights into the client-system and its problem led to the initiation of a new cycle.

In addition to identifying critical dimensions of architectural knowledge, an insight emerged that the improving the boundary-spanning competence of vendors was critical for alleviating the problems that transport organizations experienced. It was also clear that the existence of proprietary interfaces obstructed potentially innovative and value-creating vendor interactions. Since the AR project aligned the majority of the technology vendors available, some suggested that the project an arena for the development of an industry standard.

5.4.2 SECOND ACTION RESEARCH CYCLE

Based on the evaluation of the outcome of the first AR cycle, the AR-team agreed to undertake a second cycle. A diagnosing phase consisted of a comparative analysis of vendors' proprietary software interfaces. This analysis was intended to further clarify how proprietary interfaces could hinder a common architecture. The analysis showed that application interfaces from stationary vendors were lacking descriptions of technological capabilities outside the stationary context such as fuel consumption metrics or working time data. This could explain why such capabilities did not become part of current UCE innovation. In view of this analysis and the insufficient results from the previous action, the second AR cycle was guided by the working hypothesis that: *The instantiation of architectural knowledge through IT bases spanning standards is a necessary complement to boundary-spanning communication channels and filters in UCE innovation.*

Based on the diagnosing phase, a plan for designing a standardized "mobile stationary interface" (MSI) utilizing component knowledge from all actors in the industry network was devised together with the AR-team. Together with technicians and managers from all vendors and transport organizations, I managed the prototype development. MSI was intended as an instantiation of architectural knowledge across the earlier specified dimensions of technology capability awareness, user context sensitivity, and business model understanding. MSI should thereby promote boundary-spanning innovation by creating an inclusive coupling of the stationary, mobile, and embedded components of the overall UCE architecture. Apart from such coupling, it was imperative to recruit a user organization with first-hand experience of integration projects to the industry network. To this end, the AR team identified and recruited TRB, a consultative organization owned by 16 transport organizations incorporating a sizeable part of the Swedish fleet.

To maximize the diffusion potential of MSI, development was grounded in technological solutions familiar to the industry network. Extensible markup language (XML) was the basis of a number of vendors' application interfaces and more were in the process of adopting it. XML was therefore chosen for MSI development. The subsequent development was conducted by researchers and informed by clients. Suggestions for improvements were discussed by user organization and vendor representatives in project and work meetings. Some were implemented in a prototype interface. This prototype was again subject to discussions. In total, 6 such iterations of MSI development were performed. Overall, the interface prototypes specified a common business terminology for inter-system communication of transport activities and their relationships. For instance, sensor data from embedded systems such as gear shift metrics, maintenance timing, and fuel consumption were intended to augment a goods-centered and stationary representation of transport assignments.

The evolving architecture as suggested by MSI prototypes forced the vendor organizations to reflect on new types of problems. Indeed, the existing knowledge and relations in the industry network were disputed. The contents of dimensions of architectural knowledge as envisaged in the first cycle were changing, indicating a growing boundary-spanning competence. In particular, there were three episodes pertaining to technology capability awareness, use context sensitivity, business model understanding, that illustrate this change. First, the instantiation of technology capability awareness provided by MSI enforced new views of the limitations of current levels of awareness of technologies and their potential. As an example, the service capability innovation pertaining to working time management of embedded technology such as digital tachographs was discussed. Initially, MSI included an idea of relations between working time scheduling services in stationary systems and dynamically recorded data from embedded technology in trucks. However, the industry network reacted negatively as it became evident that no organization could adequately conceptualize such relations. Thus, dynamically generated embedded data for working time management were removed from subsequent versions of MSI. This embedded technology fell out of scope as its capabilities could not be substantiated into service innovation.

Second, MSI development forced the industry network to revisit their current use context management. Several user organizations pointed to the need of localization of a number of standard business terms due to perceived differences in practice. In essence, this pointed to the need of being able to switch mobile-stationary terminology to firm-specific local conditions. In response, MSI incorporated a separate “context schema”-mechanism. This mechanism provided a potential to adapt a number of business terms by referring to a locally defined context XML schema in any given mobile-stationary communication. However, the existence of such a feature in the emerging architecture incited a debate on whether stationary, mobile, or embedded vendors were responsible for defining and managing local contexts. Ultimately, MSI was designed according to the idea that that was a stationary vendor responsibility.

Third, present business models were influencing MSI development. Evidently, embedded vendors viewed sensor data captured by their embedded systems in use as a vendor resource, rather than the property of the transport organization. By incorporating such data, MSI threatened to make it available to others with considerably less effort than previously. This threatened to invite service innovators primarily operating within other components. Embedded vendors consequently adopted a hesitant stance. Increasingly tough negotiations stalled the process. Customer pressure leveraged by TRB proved decisive. They conceptualized the inclusion of embedded systems data as new and viable business relations. In doing so a compromise could be reached that allowed the inclusion of embedded data viewed as relevant to a transport assignment. Fuel consumption data was included in MSI, but high-resolution data used for other purposes such as vehicle maintenance and engine development was excluded. Through this arrangement, vendors of embedded technology gained what they considered an acceptable innovation leeway.

An important assumption in entering the second action research cycle was that a collectively developed mobile-stationary application interface would remove proprietary interfaces' limiting influence on boundary-spanning interaction. This assumption was put to the test as a major stationary technology vendor initiated a series of events culminating in their leaving the industry network. These events were indicative of emerging architectural knowledge at an inter-firm level with potential to redefine the existing competitive logic of systems integration. During a project meeting in September 2005, and outside the agenda, the stationary vendor announced that they were in the process of investigating whether the MSI prototype constituted an infringement of intellectual property rights in relation to their proprietary interface. Indicating it was they called for an immediate halt of the ongoing development. The MSI development process was thus suddenly in jeopardy. Progress slowed to a standstill as the actors in the industry network tried to establish the validity of this claim. However, initial remarks indicated that no such validity was found and after three months it became evident that the actions of the stationary vendor were in fact counterproductive. Terminating this episode, the remaining actors in the industry network collectively confronted the stationary vendor in a letter of intent stating that the project would continue with or without their involvement. The stationary vendor chose to revoke initial claims and declining to take further part, they left the industry network in November 2005.

The remainder of the project group pressed on with renewed strength. MSI was put to the test in two pilot integrations performed during the summer of 2006. IBS and Vehco systems were integrated in one setting, and Locus and Vehco in another. I was granted access to the process and performed several interviews with involved personnel from vendors and user organizations alike. In both of these field assessments, the use of MSI changed the accustomed relation between stationary and mobile vendors. A change of practice indicated a shift from a previously dominant stationary perspective. Stationary actors involved were increasingly perceiving their knowledge of technologies, use contexts, and business models as a component in a larger environment composed of other components with a broader range of complimentary capabilities. In August 2006, the results of the test cases were presented at the annual trade fair. In a public presentation, one manager from an involved user organization recognized the interface standard as a means of clarifying roles and relationships among vendors. MSI thus facilitated requirements specification and deliverables, combining heterogeneous technologies into a coherent information environment. Following the trade fair, “MSI Group” - a consortium consisting of the industry network, attracted attention from trade press and transport organizations and vendors alike.

Moreover, following experiences gained through the project, Volvo abandoned attempts at competing in the stationary IT base instead concentrating fully on mobile and embedded component development. By the autumn of 2007, the industry network had been transformed into a commercial consortium. The MSI initiative had received increasing attention from trade press and was well known in the Swedish road transport industry. New membership applications are currently being considered and a substantial expansion is planned. The early dependence on active researchers was gradually phase out as actors in the industry network increasingly perceived the effort not only worthwhile, but also resilient considering its effects. Though outside the scope of this research, there is reason to believe that the effects on the client system are sustainable.

Action Research Cycle 2 (July 2004 to August 2007)

Research collaborators:

Viktoria Institute, Hogia, NL Partner[3], Scania, Vehco, Volvo Trucks, IBS, MobiOne, Mobistics, Transics, and Transware

Data sources:

Project meetings	16
Work meetings	36
Interviews	21
Workshops	3
Technical documents	Proprietary interface documentation MSI prototype interface specifications

Phase 1. Diagnosing

Interfaces dominated by stationary perspectives form unilateral boundary objects that obstruct the enactment of boundary spanning architectural knowledge. The following working hypothesis was formulated: *The instantiation of architectural knowledge through IT bases spanning standards is a necessary complement to boundary-spanning communication channels and filters in UCE innovation.*

Phase 2. Action planning

An iterative development of a standard interface for the Swedish transport industry called “Mobile-Stationary Interface” (MSI) was planned. Vendors were to contribute proprietary interfaces which were to be combined and refined by researchers. Evaluation would be performed by the client-system.

Phase 3. Action taking

A total of 6 versions were presented and revised following feedback as MSI prototypes were presented to vendors and road haulage firm representatives of the client-system.

Phase 4. Evaluation

MSI was subsequently integrated with vendor systems in two parallel trial integration projects. The MSI group was established as a formal standardization organization.

Phase 5. Specifying Learning

The working hypothesis was supported. Through rearranging the initial situation of proprietary interfaces, a common standard interface was developed, influenced by architectural knowledge from all components. The provisioning of innovation leeway was found to be imperative to success.

[3] NL Partner was acquired by Locus Scandinavia in late 2005.

6 Summaries of Research Papers

This thesis is a collection of peer reviewed papers published in international IS journals or acclaimed conference proceedings. These papers have been published throughout the project as a means for continuously ensuring the validity of the lessons learned throughout the AR cycles with respect to the academic community. In this vein, I have actively sought venues in which research concerning the interweaving of heterogeneous technologies was in focus. This section briefly introduces the individual papers and relates their individual contributions to the overall scope of this thesis. The papers are introduced in order of appearance.

6.1 First paper summary

This paper is built upon research performed in the first AR cycle. Intended to increase understanding of the problem situation initially indicated by clients, the study presented is of an exploratory character. Empirical data consist of 15 interviews with managers of transport organizations through which an understanding of required IT infrastructure capabilities of ubiquitous computing was sought and gained. The paper contributes managerial implications for organizations attempting to implement a UCE and serves to give the reader of this thesis an insight into UCE as perceived by road haulage organizations. Of particular interest to my research was the realization that there were very few attempts to realize any form of UCE in the partaking organizations. Instead, interviewees frequently choose to recount stories of misunderstandings and poor contextual knowledge of the part of vendor organizations. The conceptualization of a mobile-stationary divide separating the mobile and stationary parts of these organizations and their information technologies emerged as an insight that helped form the diagnose of the initial problem situation.

Andersson, M. and Lindgren, R. "The Mobile-Stationary Divide in Ubiquitous Computing Environments: Lessons from the Transport Industry," Information Systems Management (22:4) 2005, pp 65-79. Special issue on ubiquitous computing

6.2 Second paper summary

Still operating within the first research cycle, this paper targets the challenges of attempting to innovate business propositions by combining stationary, mobile, and embedded technologies by organizations in the client system. This was a first attempt alleviate the problem situation in the client system by opening up communication channels were there had been none. As a first action, vendor organizations allowed access to what they perceived as cases of successful attempts at UCE implementation. Analyzing the empirical data from the study, the challenges as conceptualized in diagnose were still evident as unintended consequences of UCE introduction. Specifically, in this paper I explore how constant availability of information in multiple social and physical contexts impacts organizational practices. The ensuing analysis of enactments of UCEs reveals both intended and unintended outcomes. Reflecting on the contradictory outcomes identified, the paper contributes to this thesis implications of integration of heterogeneous technologies for user organizations.

Andersson M. "Enacting Ubiquitous Computing Environments: A Practice Lens Analysis," Scandinavian Journal of Information Systems, first round passed.[4]

6.3 THIRD PAPER SUMMARY

This paper explicates important lessons learned from the first cycle of the project. The attempt at providing new communication channels proved to be inadequate to alleviate the problem situation. However, the results were not entirely negative as a new forum had indeed developed after the initial action taken. However, the effects were not conclusive as to affect the practice of implementing information technologies in the client system. In particular, the third paper focuses on the industry-level problem of multi-contextuality in UCE. The capability of organizations to derive value from context information depends on boundary-spanning, i.e., processes involving individuals or groups of individuals being able to transform such information into meaningful organizational action through their enacted and situated knowledge. In this vein, this paper presents an interpretive case study of client system road haulage firms and technology vendors that explores the everyday role of sensor technologies in boundary-spanning in distributed settings. Of particular interest to the forthcoming second action research cycle was the illumination of industry-level conflicts of interests as a result of utilizing identical base technology in heterogeneous contexts. This was an important lesson learned that helped inform the concluding action research cycle.

---

[4] This paper is an extensive rewrite of a previous publication: *Andersson, M., Lindgren, R., and Henfridsson, O. "Assessing the Mobile-Stationary Divide in Ubiquitous Transport Systems," in "Designing Ubiquitous Information Environments: Socio-Technical Issues and Challenges", IFIP TC8 WG 8.2 International Working Conference, Springer, Cleveland, Ohio, U.S.A., 2005, pp. 123-138.*

Lindgren, R., Andersson, M., and Henfridsson, O. "Multi-Contextuality in Boundaryspanning," Information Systems Journal, special issue of Information Systems Journal on managing knowledge in distributed environments, in press.

6.4 Fourth paper summary

This paper relates to events in the second and concluding action research cycle. Based on the lessons learned in the first cycle, a new action was undertaken in which a boundary object in the form of an application interface was developed. This mobile stationary interface was designed to break the problematic situation by clarifying the role and potential of the diverse IT bases found within the client system. I held the main responsibility for the prototype development while actors in the client system provided input and feedback. This paper accounts for how the action performed relates to recent relevant ubiquitous computing findings. Operating according to the logic of their own IT base, each of the vendors was subject to the limitations imposed by their own architectural knowledge. In this paper, an alternative approach was explored as a means to counter the interpretational inflexibility of a 'closed pipe' (Banavar et al. 2005) approach to UCE development. In practical terms, this was accomplished through a collaborative action involving actors from stationary, mobile, and embedded IT bases. In terms of the overall action research project, this paper contributes a description of the process of promoting the emergence of common architectural knowledge within the client system. In particular, the importance of securing innovation leeway for individual firms participating in UCE innovation is shown.

Andersson, M. "Leveraging Ubiquitous Computing Environments through a Mobile-Stationary Interface," (Submitted journal manuscript developed from: *Andersson, M. "Negotiating Context: Leveraging Ubiquitous Transport Systems through a Mobile-Stationary Interface," The 14th European Conference on Information Systems, Goteborg, Sweden, 2006. Presented at the Mobile Communication, Telematics and Ubiquitous Computing track*)

6.5 Fifth paper summary

Concluding the two cycles of the action research project, this paper presents the lessons learned through the practical actions applied with respect to IT innovation and architectural knowledge. In doing so it draws on experiences from all actions taken throughout the whole 60 month project. Revisiting Henderson and Clark's (1990) theory of architectural innovation, a theoretical perspective is developed that helps to explain the development of architectural knowledge in UCE settings. This concept of architectural knowledge is found to be dependent on four components; technological capability awareness, use context potential, business model understanding, and boundary spanning capability. Technological capability refers to knowledge of the capacity of the technology of a given IT base. Use context potential refers to knowledge of applications of base technologies for given purposes in a certain industry. Business model understanding refers to the business scope of problems that can be solved by applying the two former categories of know-how. Finally, boundary spanning capability refers to the ability of a given organization to collaborate fruitfully across IT bases. As the scope of UCE development is likely often larger than any one organization can encompass with respect to technological capability awareness, use context potential, and market development skills, architectural knowledge development is particularly complicated to come by in such settings. Indeed, industries containing no central node in the form of a powerful innovator are likely to end up in multiple factions. These will attempt to design architectures dictated by the architectural knowledge of the incomplete amount of IT bases available. The actions performed throughout this project are explained in some detail and the outcome is spelled out in practical as well as theoretical dimensions. It is shown that gaining understanding of the specifics of the architectural knowledge pertaining to other's capabilities changed ingrained views and facilitated collaborative development of architectural knowledge in the firms under study.

Andersson, M., Lindgren, R., and Henfridsson, O. "Architectural Knowledge in Heterogeneous IT Innovation", Journal of Strategic Information Systems, in review (second round)

7 Contributions

The goal of the research presented in this thesis has been to uncover innovation processes in the context of UCEs. Answers to the research question "*How can architectural knowledge be developed in industries characterized by heterogeneous IT bases?*" were sought and gained by grappling with the richness of empirical problems faced by an emerging industry composed of multiple vendors of various technologies and the organizations using them. In this concluding section, I will present the main contributions of this thesis. In line with the dual goal of action research (McKay and Marshall 2001), the results of this research carries implications for research and practice alike. First, it shows how the collective achievement to develop UCE can be understood in terms of aligning fragmented architectural knowledge. Second, based on the lessons learned throughout my research, I will extract some implications for strategy. Finally, a practical outcome of this research is the creation of the "Mobile-Stationary Interface Group", a consortium of user organizations and vendors of stationary, mobile, and embedded IT components and truck manufacturers governing an interface standard that is currently being made available to the transport industry.

7.1 IMPLICATIONS FOR THEORY

A mounting body of literature on UCE has addressed its impact on customer relationships (Gershman and Fano 2006), supply chains (Roussos 2006a), and value networks (Jonsson et al. in press). Contributing to this stream of inquiry, this thesis provides a perspective on architectural knowledge in heterogeneous IT innovation. Based on Henderson and Clark's (1990) model of architectural innovation, a UCE is conceptualized as an assemblage of core components dependent on a common architecture. However, with the objective of explicating the emergence of architectural IT innovation in UCE settings, this framework is extended to incorporate heterogeneous IT components. Importantly, each of these components include not only an IT base (Lyytinen and Rose 2003), but also knowledge of technology, market, and industry relationships. Though a prerequisite for UCE innovation, these complex components are typically not designed for this purpose. Rather, they have evolved subject to the actions and rationale of an associated network of organizations. In recognizing this, a distinguishing characteristic is that any given UCE component independently delivers end user value to an associated market. In this vein, my research complements that on heterogeneous infrastructures where component interdependency is central for generating value (Yoo et al. 2005). Based on these conceptualizations of components and relations, a research model of UCE innovation is constructed. This model contributes to the IT innovation literature a formalization of heterogeneous IT innovation in a UCE setting.

The theoretical understanding of the heterogeneous nature of UCE innovation conveyed by the research model was used as guidance in two successive action research cycles designed to alleviate the practical problems faced by the client system of organizations. Analyzing the outcome, four dimensions of architectural knowledge, critical to UCE innovation processes emerged. These were *technology capability awareness, use context sensitivity, business model understanding*, and *boundary-spanning competence*. These dimensions can be categorized further as the first three dimensions define subsets of architectural knowledge, while boundary-spanning competence designates a capacity to form such knowledge across IT bases.

Technology capability awareness refers to actors' perception of the base service capability of a specific component IT base. Such awareness of capabilities is crucial to innovate within a given component. For instance, know-how of the capacity of core mobile platforms and communications protocols is crucial for the development of mobile text messaging services. The formation of this awareness is constrained by prior experiences, or technological frames (Orlikowski and Gash 1994), pertaining to core technologies of the component IT base in question.

Use context sensitivity refers to the understanding of use contexts in which a specific IT base component is typically deployed. As an example, important contexts for embedded technology such as diagnostics is maintenance and product development, and knowledge of this work practice both enable and constrain service development based within this component.

Business model understanding refers to the appreciation of business opportunities afforded by applications of a component IT base (cf. Fleisch and Tellkamp 2006). Such an understanding is shaped by continuous interaction within a market associated with the given component. For instance, various vendors of stationary business systems compete by improving their stationary service components, thus forming and sustaining a stationary innovation trajectory.

Mastery of these three dimensions of component knowledge is crucial to successful service innovation within the realm of any given UCE component. However, UCE service innovation necessitates a combination of knowledge of independent components. While stationary, mobile, and embedded components may offer the independent business solutions necessary they are not sufficient for UCE innovation processes to take place. Architectural knowledge is a key ingredient in UCE innovation in that it must span component knowledge crossing the boundaries of heterogeneous IT components. However, this boundary spanning aspect of developing UCE architecture can be challenging for individual firms, because learning with respect to new outside information is largely a function of their prior knowledge (Cohen and Levinthal 1990), knowledge based on experiences gained from within a UCE component. *Boundary spanning competence* helps redefine component knowledge in view of knowledge associated with other components of the architecture. Thus, it refers to practical skills and resources that can be utilized in collective efforts to develop architectural knowledge in an industry.

In practical terms, this intertwining of heterogeneous component knowledge conveys a participating organization an architectural knowledge enriched by technology capability awareness, use context sensitivity, and business model understanding that have emerged in other components. For instance, with regards to technology capability awareness, the know-how of mobile IT components can be utilized to produce applications exploiting these capabilities for services such as text messaging or remote access to stationary enterprise systems. Furthermore, a use context sensitivity that is enhanced by boundary spanning capacity encapsulates an understanding of the fact that multiple use contexts of ubiquitous computing technologies may exist. For instance, remote diagnostics data can also be used by the technology vendor for internal product innovation purposes but also to enhance stationary IT services with dynamic field data.[5] Finally, architectural knowledge enhanced by boundary spanning facilitates the reconsideration of business model understanding. In the MSI case, embedded vendors gradually gained such understanding by revising their initial view of sensor data as a means of generating novel in-house services only.

These subsets of architectural knowledge forms a foundation upon which trading zones (Galison 1997; Kellogg et al. 2006) can emerge in which heterogeneous actors can carry out of new combinations of preexisting components. Indeed, the project environment became a physical and cognitive arena "for communities with separate innovation trajectories to negotiate, collaborate, and learn through mutual perspective making and taking" (Boland et al. 2006, p. 635).

The development of communication channels connecting industry actors in the client-system in the first action research cycle enabled boundary spanning communication of component based subsets of UCE-related architectural knowledge. However, effects on the practical problem situation as diagnosed were limited. Vendors were cautious to engage in any developments that threatened the validity, and business models, of the architectural knowledge they currently held. The channels formed an unstructured trading zone in which multiple views or "organizing visions" (Swanson and Ramiller 1997; Swanson and Ramiller 2004) of limited scope competed. Essentially these visions were confined to the scope of architectural knowledge as evident in these originating components.

It was not until the second action research cycle that boundary-spanning competence-building was evident. The mobile stationary interface developed throughout this cycle evolved into a boundary object that enabled innovation among these heterogeneous actors. It instantiated the architectural knowledge developed throughout the project allowing actors to combine knowledge of their respective innovation trajectories. In sum, the MSI project entailed the advancement of

5 This type of multi-contextuality in use is further explained in the third paper of this thesis.

knowledge about the role and nature of architectural knowledge in integration of heterogeneous technologies. The research model presented in this thesis conceptualizes heterogeneous IT innovation. In doing so, it provides a basis for expanding this understanding and testing its applicability in similar settings of heterogeneous IT innovation.

7.2 Implications for strategy

This research has shown that a tumultuous and biased market can be stabilized by collectively designing and accepting an architectural design in which the capabilities of crucial IT bases are viewed as independent components, each adding clearly defined capabilities to the overall architecture of the environment. In doing so, there are a number of strategic implications concerning heterogeneous IT innovation relevant beyond this idiographic action research context.

An important strategic task is to establish a political platform that is perceived neutral enough to facilitate the emergence of architectural knowledge in industries lacking a dominant actor as a locus of innovation. Based on the experiences made throughout this project, individual organizations are well advised to consider aligning with universities, research institutes, or industry alliances for establishing such neutral grounds. It is also imperative to collectively develop boundary definitions between components of an architecture with respect to technology capabilities, use contexts, and business models. In doing so, architectural knowledge emerges as an increased capability to appreciate the conditions present in the other components, creating a foundation for boundary spanning innovation. However, this raises yet another concern in that such boundary definitions must reflect a viable common denominator. This means that any resulting formalized architecture should not pose an immediate threat to perceived core markets of any component IT base. It is therefore imperative to balance the need for open core component capabilities and requirements of innovation leeway for individual firms within their core IT base. This is typically achieved by black-boxing technology capabilities of the component IT bases, acknowledging the innovation prerogative of organizations within that particular component market. Finally, user organizations should be invited to balance the diverging market strategies found in the involved IT bases by formulating scenarios, and supplying cases. Indeed, struggles between biased proprietary architectures can be defused by increasing UCE user participation.

No account of action research would be complete without conveying the practical contributions to the client-system of the research. A significant outcome is the establishment of the “Mobile-Stationary Interface Group”, a consortium of user organizations and vendors of embedded, mobile, and stationary transport systems and finally truck manufacturers. This group is currently finalizing a Mobile-Stationary Interface (MSI) standard that is to be made available to the transport industry. There are examples of transport organizations that have piloted MSI-based integration projects. Several vendors are currently implementing the standard in their software packages and considering the implications for their business strategies. For instance, Volvo Trucks is currently aligning its telematics strategy in line with the architectural knowledge generated in the action research project. By embracing a new strategy their embedded telematics systems are to become better prepared to form part of larger architectures of multiple components from vendors of enterprise systems, geographical information systems, navigation technology, order management, and so on.

The MSI Group is now entering an expansive stage and new organizations are being aligned to the consortium. Of particular interest, negotiations are underway with new types of actors such as mobile network operators. The consortium's challenge here is not primarily to explain the technical interface but to secure that the knowledge developed be successfully shared with new entrants. This indicates that the architectural knowledge dimensions identified throughout the action research project will be of significance to the expansion of the network.

8 REFERENCES

Abowd, G.D.Mynatt, E.D. "Charting Past, Present, and Future Research in Ubiquitous Computing," *ACM Transactions on Computer-Human Interaction* (7:1) 2000, pp 29-58.

Anderson, P.Tushman, M.L. "Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change," *Administrative Science Quarterly* (35:4) 1990, pp 604-633.

Banavar, G., Black, J., Cáceres, R., *et al.* "Deriving long-term value from context-aware computing," *Information Systems Management* (22:4) 2005, pp 32-42.

Baskerville, R.Myers, M.D. "Special Issue on Action Research in Information Systems: Making IS Research Relevant to Practice - Foreword," *MIS Quarterly* (28:3) 2004, pp 329-335.

Baskerville, R.L.Wood-Harper, A.T. "A critical perspective on action research as a method for information systems research," *Journal of Information Technology* (11) 1996, pp 235-246.

Baskerville, R.L.Wood-Harper, A.T. "Diversity in Information Systems Research Methods," *European Journal of Information Systems* (7:2) 1998, pp 90-107.

Becker, S.W.Whisler, T.L. "The Innovative Organization: A Selective View of Current Theory and Research," *Journal of Business* (40) 1967, pp 462-469.

Berg Insight "“Fleet Management and Wireless M2M”," *M2M Research Series* (Second Edition, Europe 2006) 2006.

Boland, R., Lyytinen, K., and Yoo, Y. "Wakes of Innovation in Project Networks: The Case of Digital 3-D Representations in Architecture, Engineering, and Construction
" *Organization Science* (18:4) 2007, pp 631–647.

Chesbrough, H.W. "The Era of Open Innovation," *Sloan Management Review* (2003:Spring) 2003, pp 35-41.

Chiasson, M.W.Davidson, E. "Taking Industry Seriously in Information Systems Research," *MIS Quarterly* (29:4) 2005, pp 591-605.
Christensen, C.M. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* Harvard Business School Press, Boston, MA, 1997.
Cohen, W.M.Levinthal, D.A. "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* (35:1) 1990, pp 128-152.
Daft, R.L. "A Dual-Core Model of Organizational Innovation," *Academy of Management Journal* (21:2) 1978, pp 193-210.
Daft, R.L.Weick, K.E. "Toward a model of organizations as interpretation systems," *Academy of Management Review* (9:2) 1984, pp 284-295.
Davison, R.M., Martinsons, M.G., and Kock, N. "Principles of canonical action research," *Information Systems Journal* (14) 2004, pp 65-86.
Dewar, R.D.Dutton, J.E. "The Adoption of Radical and Incremental Innovations: An Empirical Analysis," *Management Science* (32:11) 1986, pp 1422-1433.
Dourish, P. *Where the Action Is: The Foundations of Embodied Interaction* MIT Press, Cambridge, MA, 2001.
Fleisch, E.Tellkamp, C. "The Business Value of Ubiquitous Computing Technologies," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business,* G. Roussos (ed.), Springer Verlag, London, 2006.
Galison, P. *Image and Logic: A Material Culture of Micropysics* University of Chicago Press, Chicago, IL, 1997.
Gershman, A.Fano, A. "Ubiquitous services: Extending Customer Relationship Management," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business,* G. Roussos (ed.), Springer Verlag, London, 2006.
Giddens, A. *New Rules of Sociological Method* Basic Books, New York, 1976.
Grindley, P. *Standards, Strategy, and Policy: Cases and Stories* Oxford University Press, New York, 1995.
Grudin, J. "Desituating Action: Digital Representation of Context," *Human-Computer Interaction* (16) 2001, pp 269-286.
Hanseth, O.Monteiro, E. "Inscribing Behaviour in Information Infrastructure Standards," *Accounting, Management & Information Technology* (7:4) 1997, pp 183-211.
Henderson, R.M.Clark, K.B. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly* (35) 1990, pp 9-30.
Hult, M.Lennung, S.-Å. "Towards a definition of action research: a note and bibliography," *Journal of Management Studies* (17) 1980, pp 241-250.
Jonsson, K., Westergren, U.H., and Holmström, J. "Technologies for Value Creation: An Exploration of Remote Diagnostics Systems in the Manufacturing Industry," *Information Systems Journal*) forthcoming.
Jonsson, K., Westergren, U.H., and Holmström, J. "Technologies for Value Creation: An Exploration of Remote Diagnostics Systems in the Manufacturing Industry," *Information Systems Journal*) in press.
Kellogg, K.C., Orlikowski, W.J., and Yates, J. "Life in the Trading Zone: Structuring Coordination Across Boundaries in Postbureaucratic Organizations," *Organization Science* (17:1) 2006, pp 22–44.
Lyytinen, K.Rose, G.M. "The Disruptive Nature of Information Technology Innovations: The case of Internet Computing in Systems Development Organizations," *MIS Quarterly* (27:4) 2003, pp 557-595.
Lyytinen, K.Yoo, Y. "Research Commentary: The Next Wave of Nomadic Computing," *Information Systems Research* (13:4) 2002, pp 377-388.

Lyytinen, K.Yoo, Y. "Social impacts of ubiquitous computing: Exploring critical interactions between mobility, context and technology," *Information and Organization* (15) 2005, pp 91-94.

March, S., Hevner, A., and Ram, S. "Research Commentary: An Agenda for Information Technology Research in Heterogeneous and Distributed Environments," *Information Systems Research* (11:4) 2000, pp 327-341.

Markus, M.L., Steinfield, C.W., Wigand, R.T., *et al.* "Industry-Wide Information Systems Standardization as Collective Action: The Case of the U.S. Residential Mortgage Industry," *MIS Quarterly* (30:5) 2006, pp 439-465.

Mathiassen, L. "Collaborative Practice Research," *IT & People* (15:4) 2002a, pp 321-345.

Mathiassen, L. "Collaborative Practice Research," *Scandinavian Journal of Information Systems* (14:1) 2002b, pp 57-73.

McKay, J.Marshall, P. "The dual imperatives of action research," *Information Technology & People* (14:1) 2001, pp 46-59.

Nelson, R.R.Winter, S.G. *An Evolutionary Theory of Economic Change* Harvard University Press, Cambridge, MA, 1982.

Orlikowski, W.J.Gash, D.C. "Technological Frames: Making Sense of Information Technology in Organizations," *ACM Transactions on Information Systems* (12:2) 1994, pp 174-207.

Rogers, E.M. *Diffusion of Innovations*, (4 ed.) Free Press, 1995.

Roussos, G. "Optimizing Business Processes by Automatic Data Acquisition: RFID Technology and Beyond," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*, G. Roussos (ed.), Springer Verlag, London, 2006a.

Roussos, G. "Ubiquitous Computing for Electronic Business," in: *Ubiquitous and Pervasive Commerce New Frontiers for Electronic Business*, G. Roussos (ed.), Springer Verlag, London, 2006b.

SCB *Enterprises with freight transport by road, storage and forwarding agencies, Financial data for 2005* Statistiska Centralbyrån, 2007.

Schumpeter, J. *The Theory of Economic Development* Harvard University Press, Cambridge, Massachusetts, 1934.

Sheremata, W.A. "Competing through Innovation in Network Markets: Strategies for Challengers," *Academy of Management Review* (29:3) 2004, pp 359-377.

SIKA *Swedish national and international road goods transport, year 2006* Statens institut för kommunikationsanalys, 2007.

Soh, P.-H.Roberts, E.B. "Networks of innovators: a longitudinal perspective," *Research Policy* (32) 2003, pp 1569-1588.

Star, S.L.Ruhleder, K. "Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces," *Information Systems Research* (7:1) 1996, pp 111-134.

Susman, G.Evered, R. "An assessment of the scientific merits of action research," *Administrative Science Quartely* (23) 1978, pp 582-603.

Swanson, E.B. "Information Systems Innovation among Organizations," *Management Science* (40:9) 1994, pp 1069-1092.

Swanson, E.B.Ramiller, N.C. "The Organizing Vision in Information Systems Innovation," *Organization Science* (8:5) 1997, pp 458-474.

Swanson, E.B.Ramiller, N.C. "Innovating Mindfully with Information Technology," *MIS Quarterly* (28:4) 2004, pp 553-583.

Sørensen, C.Yoo, Y. "Socio-Technical Studies of Mobility and Ubiquity," Designing Ubiquitous Information Environments: Socio-Technical Issues and Challenges Springer, Cleveland, Ohio, U.S.A., 2005.

Teece, D.J. "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy," *Research Policy* (15) 1986, pp 285-305.

Topi, H. "From the Editors," *Information Systems Management* (22:4) 2005, pp 5-6.

Van de Ven, A. "Running in Packs to Develop Knowledge-Intensive Technologies," *MIS Quarterly* (29:2) 2005, pp 365-378.

Van Maanen, J. "The Fact of Fiction in Organizational Ethnography," *Administrative Science Quartely* (24:4) 1979, pp 539-550.

Weiser, M. "The Computer for the 21st Century," *Scientific American* (265:3 (September)) 1991, pp 94-104.

Williams, M.Frolick, M. "The evolution of EDI for competitive advantage: the Fedex case " *Information Systems Management* (18 2) 2001, pp 47-53.

von Hippel, E. "'Sticky Information' and the Locus of Problem Solving: Implications for Innovation," in: *The Dynamic Firm,* A.D. Chandler, P. Hagström and Ö. Sölvell (eds.), Oxford University Press, Oxford, 1998, pp. 60-77.

Yoo, Y.Lyytinen, K. "Social impacts of ubiquitous computing: Exploring critical interactions between mobility, context and technology - a special issue for information and organization.," *Information and Organization* (15:2) 2005, pp 91-94.

Yoo, Y., Lyytinen, K., and Yang, H. "The role of standards in innovation and diffusion broadband mobile services: The case of South Korea," *Journal of Strategic Information Systems* (14) 2005, pp 323–353.

FIRST PAPER

1 The Mobile–Stationary Divide in Ubiquitous Computing Environments

Lessons From the Transport Industry

Magnus Andersson and Rikard Lindgren

Abstract

The emergence of ubiquitous computing offers new possibilities and opportunities for organizations attempting to improve their productivity and effectiveness. In particular, the promises of ubiquitous computing are attractive to organizations such as transport firms, in which coordination of diverse sets of mobile units is central to organizational performance. This article analyzes the use of ubiquitous transport systems in Swedish road haulage firms and discusses the opportunities and challenges for the early adopters. It pays specific attention to the mobile–stationary divide; that is, the set of challenges associated with integration of mobile and stationary people and systems into a seamless computing environment.

1 Introduction

Facilitated by rapid developments in mobile and wireless communication technologies and continuing miniaturization of computing devices, the emergence of ubiquitous computing offers new possibilities and opportunities for organizations attempting to improve their productivity and effectiveness (Lyytinen and Yoo, 2002a). In particular, the promises of ubiquitous computing are attractive to highly mobile organizations such as transport firms, in which coordination of diverse sets of mobile units is central to organizational performance.

In this article, we use an analysis of road haulage firms, a particular type of transport organization, as a mechanism to study the broader effects of ubiquitous computing on mobile organizations. The typical road haulage firm co-ordinates a workforce mainly consisting of drivers who are geographically distributed and constantly moving, providing timely pickup and delivery of goods. For a decade or so, continuous advances in mobile, embedded, and wireless technology such as global positioning systems (GPS), radio frequency identification (RFID), and embedded vehicle systems have enabled the development of a wide range of sophisticated applications supporting these daily activities (Akinci et al., 2003 ; Angeles, 2005; Giannopoulos, 2004; Roy, 2001). Tactical information technology (IT) support includes positioning of trucks and cargo, recording of performance parameters from the vehicle, and wireless communication of data from some or all of these tools. The positions of individual trucks can be displayed on maps, offering dispatchers a quick overview of the geographic distribution of the mobile resources. Route calculation done by the driver in the field or by the dispatcher is intended to minimize the cost of a transport assignment in terms of time and fuel expenditure.

Road haulage firms are an excellent example of an industry that is implementing a wide variety of distributed support tools to conduct its day-to-day business, and thus, seeking to interconnect various technological and social elements into an assemblage that enables physical and social mobility of computing and communication services (Lyytinen and Yoo, 2002a). We use the term ubiquitous transport systems (UTS) to discuss seamlessly integrated computing environments applicable to the transport industry. UTS can be described as a special case of a distributed and heterogeneous enterprise computing architecture intended to facilitate efficient and seamless integration of people and systems in a transport organization (March et al., 2000). Yet, there is limited theoretical understanding of how IT architectures can be designed to support core business activities of highly mobile organizations and how distributed computing and communication capabilities can enable such organizations to exploit resources and explore business opportunities. It is not obvious how the traditional logic of understanding IT infrastructures applies to the context of distributed and heterogeneous computing environments; thus, new experiences and insights based on a thorough understanding of the requirements of such environments are needed (March et al., 2000; Sambamurthy and Zmud, 2000).

To offer transport organizations seamless information integration and sharing in their everyday activities requires capabilities for integration of people, distributed and heterogeneous mobile and embedded technologies, and stationary transport business systems. As recognized in the literature, however, integrating traditional business and mobile computing with pervasive computing functionality into ubiquitous computing architectures is a critical challenge (Banavar and Bernstein 2002; Lyytinen and Yoo 2002b). Inspired by recent calls for IS research efforts targeted at the design, use, and impacts of mobile and wireless technology in organizations (Jessup and Robey, 2002; Lyytinen and Yoo, 2002a), we seek to understand required infrastructure capabilities of UTS (as seamlessly integrated computing environments applicable to the transport industry) and, through this example, the broader implications of ubiquitous computing technologies on organizations depending on distributed capabilities.

In view of this ambition, we have chosen to concentrate our efforts on knowledgeable managers in several Swedish road haulage firms. The rationale behind this approach is our aim to capture experiences and expectations of enterprise-wide support in the Swedish road haulage sector through the lens of influential individuals likely to have the responsibility to ensure that IT investments produce long-term organizational value in their organizations. What we set out to capture is these individuals' general notion of the role of UTS in the day-to-day practice of road haulage firms. On the basis of our empirical findings, this article discusses important insights related to infrastructure capabilities of UTS. Addressing infrastructure challenges in ubiquitous computing environments, the article contributes general managerial implications for organizations attempting to integrate mobile and stationary information systems.

This article proceeds as follows. First, it outlines infrastructure challenges associated with integration of technological and social components in ubiquitous computing environments. This is followed by a presentation of the research context and the method used. We then present expectations and experiences of enterprise-wide support in road haulage firms. Thereafter, we discuss insights related to infrastructure capabilities of UTS. In addition, we also spell out explicit managerial implications for organizations attempting to integrate mobile and stationary information systems. Summarizing our findings, we highlight important venues for future IS research on ubiquitous computing environments.

2 Infrastructure Challenges in Ubiquitous Computing Environments

The main purpose of enterprise-wide support systems is to remedy the information fragmentation of function-oriented legacy systems (Davenport, 1998). This is typically achieved by incorporating functionality, similar to that of previous legacy systems, as modules in an enterprise IT infrastructure intended to support all business activities in one bold leap. Markus and Tanis (2000, p. 173) define enterprise support systems as "... software packages claiming to provide a total, integrated solution to companies' information-processing needs." Enterprise-wide support systems can thus be described as large-scale organizational systems containing "a set of packaged application software modules with an integrated architecture, which can be used by organizations as their primary engine for integrating data, processes, and information technology, in real time, across internal and external value chains" (Shang and Seddon, 2002, p. 272). As noted by Lee et al. (2003), the notion of integrated enterprise support reflects the capability of IT architectures to integrate a variety of different system functionalities.

IS researchers have gained considerable knowledge about forces and issues influencing the design of effective organizational architectures. As recognized by Sambamurthy and Zmud (2000), however, this accumulated wisdom may be inadequate for understanding the requirements of contemporary business organizations demanding information processing capabilities that enable and facilitate management of dispersed operations, dynamic business partnerships, and integrated supply chains. Facilitated by recent advances in Internet technologies, portable information devices, and high-speed wireless communication services, these business environments are increasingly heterogeneous and distributed, requiring hybrid, best-of-breed, and adaptive architectures and platforms that provide scalability, flexibility, and openness to emerging mobile and ubiquitous technologies (see, e.g., Sambamurthy and Zmud, 2000). A key challenge for IS researchers is thus to generate appropriate insights for how to construct distributed and heterogeneous computing environments, enabling the utilization of computing capabilities with which organizations can address core information processing problems and opportunities (March et al., 2000).

According to Lyytinen and Yoo (2002a, p. 378), a ubiquitous computing environment can be portrayed as a "heterogeneous assemblage of interconnected technological, and social, and organizational elements that enable the physical and social mobility of computing and communication services between organizational actors both within and across organizational borders." Fundamental characteristics of a ubiquitous computing environment are high levels of mobility, services, and infrastructures, and the diverse ways in which data is processed and transmitted. Whereas services refers to the application of the infrastructure resources to provide a computational solution to a client's requirements, the infrastructure concerns technological specifications, standards, and protocols and their technical implementations, and institutions and communities critical for developing and sustaining such standards and technical implementations (Lyytinen and Yoo, 2002a).

The shift toward ubiquitous computing environments will render multiple novel technological, social, and organizational challenges (Jessup and Robey, 2002). At the technology level, for example, a main challenge originates from integrating traditional business and mobile computing with pervasive computing functionality into ubiquitous computing infrastructures (Banavar and Bernstein, 2002; Lyytinen and Yoo, 2002b). At a general level, traditional business computing can be described as computing taking place in fixed physical sites. In contrast, mobile computing is about increasing people's ability to physically move computing services with them. Reflecting the idea of computers having the ability to act "intelligently" relative to its surrounding context, pervasive computing is about computers being able to obtain information from the environment in which they are embedded and use it to dynamically build models of computing. An effective ubiquitous computing architecture must thus be capable of identifying, adapting, and delivering the appropriate combination of stationary, mobile, and pervasive applications to the organization's computing environment.

As recognized in the literature, at least three infrastructure challenges are associated with integration of both stationary and distributed social and technical elements as effective components of ubiquitous computing environments (Lyytinen and Yoo, 2002 a; Lyytinen and Yoo, 2002b). These are as follows:

- Providing infrastructure support for applications effectively using context information to provide organizational awareness of coexisting stationary and mobile computing environments (Dey et al., 2001). Indeed, a clear understanding of context is critical in organizational attempts to create such awareness.

- Design, integration, and maintenance of a seamless assemblage of stationary information systems and highly distributed and heterogeneous mobile and embedded computing resources with high degrees of interoperability, scalability, and reliability (March et al., 2000). As noted by Lyytinen and Yoo (2002a), "we can predict that information management in organizations will hit a new wall of complexity when organizations migrate to mobile environments."
- Developing infrastructure support, facilitating local as well as remote interactions between people and technologies (Luff and Heath, 1998). In this context, for example, it is important to find a good balance between technologies supporting asynchronous and synchronous collaboration among both stationary and mobile workers.

Viewing this literature review as a theoretical backdrop for the research problem, we can understand UTS as a heterogeneous and distributed computing environment intended to facilitate traditional business, mobile, and pervasive computing resources in transport organizations that share information and interoperate seamlessly. Thus, studying managers' expectations and experiences of UTS, we are likely to gain important insights addressing general challenges related to integration of both stationary and distributed technological and social components in ubiquitous computing environments.

3 Research Context and Method

3.1 The anatomy of Swedish road haulage firms

Road haulage firms typically transport some kind of goods from one place to another, using trucks. At first glance, these organizations appear to be similar, dealing with the same slice of reality often in similar ways. The most obvious example suggesting such similarity would be that trucks, drivers, and transport activities constitute the core of the organization. However, the road haulage business sector is far from homogeneous in that core business activities, organizational structures, and size vary. Road haulage can be characterized as a diversified line of business, covering both local distribution of goods requiring loading and unloading several times each day and long distance trans-ports for which it can take days between loading and unloading. Accordingly, the nature of work differs, ranging from rather static work in which transport activities can be planned ahead to dynamic situations in which assignments have to be communicated to the driver during the day.

Regardless of the actual setup in different organizations, a number of roles are typically found in a road haulage firm: dispatcher, driver, management, administrative personnel, and vehicle maintenance personnel. Dispatchers handle the incoming assignments and organize drivers and trucks, being the key resources involved in transporting goods. Drivers transport goods, which involves loading, unloading, driving and planning the routes, as well as interacting with clients. Managers are responsible for economic planning and follow-up. Administrative personnel handle tasks such as wages and invoicing. Finally, there are personnel involved in activities such as vehicle maintenance, supervising of fleet status, service time scheduling, and tire changing. The borders of these task-related roles are fluid. Depending on the business size, the same person can have more than one role or several persons can have a similar role. The larger the organization, the more specialized personnel you are likely to find.

According to the Swedish Road Haulage Association, in the late 1990s almost 90 percent of their members operated approximately five vehicles, indicating that most Swedish road haulers are small firms. Currently, the Swedish transport industry is experiencing changes caused by the European Union’s open market. For example, foreign transport firms have increased their haulage share considerably, which is a direct result of lower costs in nearby countries (15–20 percent lower in countries such as Denmark, Germany, and the Netherlands, and 30–40 percent lower in countries such as Poland). This cost disadvantage has resulted in minimal profitability margins for small and independent road haulage firms. In this context, contractors of haulers such as Danzas and Schenker have strengthened their market positions.

Analogous to counterparts in Europe and North America, Swedish road haulage firms are implementing different types of IT support to improve their competitiveness (Roy, 2001). However, as noted by Williams and Frolick (2001), the size of transport organizations is an important factor in that it determines the available amount of resources for procuring and administrating IT support. Whereas UPS spent approximately $1 billion (USD) annually during the 1990s, smaller companies do not have and cannot afford to invest this amount of money to secure the same technical advantage. As a practical implication, Swedish road haulage firms rarely can afford to develop a custom-built system, forcing them to consider the various off-the-shelf solutions available. Yet the wide variety of business activities in road haulage firms can make this choice complicated, especially for small organizations. Nevertheless, it seems that road haulers try their best to overcome such struggles associated with implementing diverse technologies, indicating a desire to explore the potential benefits adequate system support could bring.

3.2 RESEARCH CASES AND METHODS

The primary method of data collection for this study was semi structured interviews, lasting between one and two hours, with key business and technology managers in 12 road haulage firms in the fall of 2002 . We selected these firms based on recommendations from the Swedish Road Haulage Association, representing approximately 11,000 road haulers with some 30,000 vehicles and machines. Whereas all of these organizations used IT support as a means for improved business performance, they were diverse in terms of core business, structure, external relations, and size. Our data collection was also informed by an IS literature review in a search for research contributions addressing enterprise architectures in highly mobile organizations. This review included top IS conferences and journals and covered the period between 1990 and 2004. More details about our research methods and descriptions of the 12 case studies can be found in the appendix.

4 THREE MAJOR IT SERVICE CHALLENGES

Three major IT service challenges identified from the interviews with the 12 road haulage firms are discussed, along with selected quotations from the managers we interviewed. (The appendix contains brief descriptions of the organizations referred to here by letters only.)

4.1 IMPROVE MOBILE RESOURCE EVALUATION

As noted by the respondents, management of an inherently mobile workforce and equipment is a delicate issue in the road haulage business. Addressing this issue, several managers saw technology as a means not only to get a better view of the field of operations, but also to enforce and evaluate company routines and policies (organizations D, E, I, J, and L). Technologies such as GPS and embedded vehicle systems were seen as enabling technologies to make visible the consequences of patterns of action in a wide variety of field activities. This includes information about activities of human actors as well as information pertaining to the mobile equipment; that is, trucks and associated hardware. An illustrative example of the former is the reports created by drivers stating their working hours. In fact, most of the road haulage firms included in the study used dedicated IT support for the actual wages calculation. However, a recurring topic among the respondents was the difficulty to check if the reported working hours were correct. Potential problems associated with the privacy of the drivers seemed important; however, although such aspects were acknowledged, the benefits were assumed to outweigh the potential social problems that may arise. The following account from the manager of organization E depicts the experience of an embedded vehicle system capable of monitoring driver activities:

The main reason why we invested in onboard computers was the reporting of working hours. [...] Most drivers are really good at reporting, but you know, fifteen minutes here and there. Fifteen minutes a day per employee and year amounts to quite large sums. We've had drivers reporting both seven and eight hours extra per week. [...] We can see when they have started [working] and we think that it's good because it's fair on the drivers. I think that those who have nothing to hide have nothing to fear.

Interestingly, managers from organizations E and L claimed that this embedded technology was also beneficial to drivers in that such systems offered them an opportunity to check detailed records for errors. The manager from organization E said:

This only makes it easier for them [the drivers]. They don't need to worry about anything else than pushing these buttons. Then they get a list that they check before the salary is paid. If there's a discrepancy, they can point that out.

Considering driver–vehicle interaction, many of the managers interviewed highlighted challenges related to the use of technology support for minimizing fuel consumption. In particular, sustaining an approved driving behaviour was viewed as difficult, because drivers frequently reverted to undesirable habits. There was also an experienced trade off between carrying out assignments as quickly as possible and driving as economically as possible. Several systems vendors offer dedicated applications to provide drivers with instant feedback on driving performance, thus constantly enforcing company policies. Presenting this information to management, these systems also facilitate managers' or dispatchers' monitoring of individual drivers' performance, further strengthening the control of driver behaviour. However, as recognized by our respondents, the outcome of field activity in terms of fuel consumption and related costs are a combination of human and machine performance.

Technology support for monitoring vehicle performance was a topic discussed by several respondents (B, D, J, and L). Because road haulage is a resource-heavy business, maintenance of vehicles is crucial. Embedded vehicle systems target precisely this, because they in essence make the equipment itself convey its condition. The ability to correctly plan maintenance to avoid costly breakdowns or untimely rescheduling is vital, and stationary systems geared with planning and follow-up features, as discussed by the manager of organization D, were used by many:

We have a really good maintenance program now. You put in anything you want and you get service orders, when the vehicle is up for service and testing and so on. And you also get a lot of historical accounts of costs, like if some vehicle is expensive regarding tires or fuel or something. That's really good actually. The next step might be to connect it directly to the vehicle, as Volvo and Scania are doing, so that you don't have to feed all this data into it. That's excellent.

In this case, knowledge of the possibility to employ embedded vehicle systems to automatically record and receive maintenance-related vehicle data raised the expectation of further improvements by reducing manual handling. However, few respondents saw any immediate feasibility of such improvements. This was attributed to the fact that most road haulage firms had a mixed fleet of trucks. Discouraged by incompatibility issues between different embedded vehicle systems for different truck brands and associated stationary systems, most of the interviewees did not intend to invest in such technology.

Beyond the evaluation of drivers or vehicles, assemblages of technologies (such as GPS, mobile communication, embedded vehicle systems, and office systems) were seen as enablers of detailed and timely follow-up on field activities directly connected to business goals. Generally speaking, the distributed mobile nature of road haulage firms makes it difficult to assess organizational performance in detail; that is, the net profit of individual assignments. To accurately gauge the performance of drivers and vehicles, managers relied on dispersed sources of information in disparate formats, ranging from computerized information to paper documents. Not surprisingly, respondents frequently lamented the difficulty of planning future action based on incomprehensive, dated, and imprecise information on internal performance (C, D, E, F, J, and L). However, discussing the relations between embedded vehicle systems and stationary business systems, the manager of organization E illustrated an awareness of the great potential of the two combined:

I think that when you have access to all these statistics [in a system], you could find informative ratios. You earn less on some transports, of course, but it would be interesting to see. If you get a comprehensive view of the costs, including work hours, then you can see how capable and efficient a driver really is. You need to include the cost of salaries when you calculate how profitable a transport is. Costs for service and repairs should also be included, because you need to see when the vehicle is becoming expensive, when it gets unprofitable.

Essentially, this support requires joint contextual information on both driver actions and vehicle performance coupled to the stationary systems. However, none of the road haulage firms in the study had been able to accomplish fully such computational support, connecting cost to income. There was also widespread concern about the difficulty involved in interpreting contextual data for evaluation purposes (C, E, F, G, H, and L). Using fuel consumption as an example, the manager of organization E highlighted the need for comprehensive information to obtain meaningful metrics on driver efficiency:

Fuel consumption [data from an embedded vehicle system] is nice to have. But it varies depending on what kind of trailer the driver has attached, the tires he has and which route he drives, and the like, so it is very hard to get a just picture.

Arguing that an acceptable representation of field activity largely depends on the specifics of the various environments, several managers considered simplified context parameters to be of limited use.

4.2 Facilitate seamless transport data management

Furthermore, technology as facilitator of seamless transport data propagation by automating presently manual tasks was a frequent topic of interest among the respondents. A primary concern was the amount of time elapsed from completion of a transport assignment to invoicing. Without the assistance of reliable wireless communication, invoicing was generally not possible until the driver returned to the office with the required documents. Depending on the character of the assignment, this could take days. Interviewees frequently mentioned the detrimental effects of delays in this process on the cash flow of the firm. In addition, manual handling of such documents was demanding in terms of personnel (A, B, D, E, G, I, and K). Indeed, such documents went lost at times. Expectations of the gains of technology were high in this area, and the manager from organization G regarded this as the main reason to invest in mobile IT:

Why do we need this type of system? So that we can send the bills earlier, that’s why. That’s the only reason; otherwise we can use pen and paper. We want to send the bill as soon as the transport is carried out, that’s where we can make money. The rest of the system is not very important just as long as it makes us able to bill five to ten days faster. If we can shorten the invoicing time five to ten days, the investment in a system would not be a great burden.

However, according to some respondents, there is a common lack of system integration involved in handling transport data (A and E). With separate systems, time-consuming and error-prone manual input or transfer of data was required. In the following quote, the manager from organization E expresses his frustration over the fact that the main customer’s order handling system was not integrated with the local cargo planning system, forcing dispatchers to manually transfer data between the two systems:

We cannot sort of connect [the system] by pushing one button, export [data] from the transport order system to the cargo planning system ... this must also be possible to do. So far we can only read the orders, print them, and then we enter the orders into our cargo planning system manually.

Pursuing a strategy of selecting an assemblage of mobile and stationary systems to facilitate seamless transport data management from a best-of-breed perspective was considered problematic (A, D, E, G, J, and K). According to the managers who had tried such a strategy, vendors frequently claim that the best solution is to implement their full systems suite, regardless of the vendor's core competence. This was not necessarily the opinion of the road haulers, who wanted the best technical solution available for each and every organizational function, be it stationary or mobile. The manager from organization K discussed personal experiences of that nature regarding a primarily mobile systems vendor:

They have been confined to their own world. I mean, if we're to have something in the truck, it must be something that we can adapt to what we have in the office ... our traffic control system. They have been unwilling to do that and have suggested that we should use their stuff both in the vehicles and in the office, and that has not worked for us.

Although technology was attributed the ability to facilitate seamless transport data management, existing problems associated with the integration of both mobile and stationary systems were seen as prohibitive. A contributing factor asserted was the complexity created by unresolved problems related to standards and specifications of mobile and stationary technologies, making advanced solutions too complicated to realize. As a consequence, the vision of an uninterrupted flow of information between distributed workers and office personnel was at best only partly realized.

4.3 Rationalize dispatcher–driver communication

A key aspect in road haulage is the communication involved in the execution of transport assignments. Information about assignments must be transmitted from transport buyers to dispatchers, between dispatchers and drivers, and from drivers to goods receivers. In many road haulage firms, much of this interaction is still handled by phone. However, several respondents considered this heavy telephone usage both stressful and time consuming (A, D, H, I, K, and L).

Describing the current situation at his firm's dispatch office, the manager of time-consuming and error-prone organization D pointed out the potential increase in efficiency by reducing dispatchers' verbal communication with drivers:

There are many incoming calls to the office, which is problematic. Not only do the drivers call but also customers and contractors of haulers and what have you. It can be quite overheated there. So, although it sounds strange, the idea is that we try to talk to the drivers as little as possible ... just so that the situation becomes both effective and manageable.

Technology was perceived to have the ability to address this communication overload in two ways. First, technology was assumed to have the potential to reduce verbal communication through the transmission of formalized messages (A, D, I, K, and L). One problem associated with verbal (i.e., telephone-based) communication is dispatchers' time spent failing to reach drivers already engaged on the phone or working outside the truck. By sending text messages, dispatchers need not rely on synchronous verbal communication. Written data was also perceived to be more exact than spoken messages, thus reducing potential misunderstandings. As illustrated by the manager of organization A, facilitating this type of communication between dispatchers and drivers was important:

[It is important] to get the orders out and communicate with the drivers in an easier, smoother way so that the communication involved in dispatching becomes easier. They [the dispatchers] are spending two hours a day talking to the drivers using mobile phones — get rid of that. Dispatchers are really stressed these days and we need to reduce their workload.

Second, technology was attributed the possibility to entirely eliminate the need for verbal communication in certain types of information gathering (A, L, and D). Before communicating new transport orders to drivers, dispatchers need to gather information that is vital for the allocation of assignments (e.g., the location of individual trucks and drivers). In contrast to the transmission of formalized messages, which still demands limited human interaction, joint positioning technology (i.e., GPS), mobile transport management systems, and embedded vehicle systems facilitate automated transfer of information from vehicle to dispatcher. In this way, the mobile context would be at hand at all times to the stationary actors. According to the manager of organization D, this would certainly play a part in increasing communication efficiency on behalf of both dispatcher and driver:

A dream would be to have a complete map over the whole district. Then you could see the vehicles, how they move, and how much cargo they carry. That would have been perfect; it would *make their job so much easier. Although you can never replace humans, a lot can be done to assist a person in taking decisions and making choices.*

However, the respondents also saw limitations to the rationalizing potential of technology. Although system support for data transfer between office and trucks was believed to reduce phone communication between driver and dispatcher, some interviewees argued that such technology would not make verbal communication redundant (A, I, J, and K). First, the respondents assumed that some forms of communication do not fit into the format of formalized messages (i.e., discussions and complex questions). Second, road haulage firms have communication needs crossing the boundaries of their own organizations. Whereas transport buyers transmit information to dispatchers, drivers contact the client at the delivery site before arrival. As noted by several managers, external communication partners cannot be supposed to share a system for electronic data transmission. The manager from organization A said:

The clients demand that he [the driver] can call when under way. I would say that they call three or four clients out of ten. Regardless of what kind of mobile communication system we get, they can never manage without the mobile phone.

Thus, in spite of the rationalizing potential of system support with regard to communication, respondents asserted that drivers will always need mobile phones for certain forms of communication.

5 DISCUSSION: THE MOBILE– STATIONARY DIVIDE

5.1 INTEGRATION CHALLENGES

In this research, we studied infrastructure capabilities of UTS in Swedish road haulage firms to gain insights about the relevance for general infrastructure challenges in ubiquitous computing environments. Clearly, our respondents' expectations regarding technology support were high, and they assumed a positive impact on several key business activities. However, as noted, the organizations studied were diverse in terms of size, core business, and external relations. Whereas differences in core business seemed of limited importance to the expectations of our respondents, size was a frequently mentioned deterrent in terms of technology investments or in-house development. More important, the nature of external relations coupled with the frequent reactive stance to various technology investments affected expectation levels with regard to UTS service requirements. Elaborating on integrated computational solutions to the service requirements of their firms, the interviewees foremost saw technology support as a means to improve mobile resource evaluation, facilitate seamless transport data management, and rationalize dispatcher–driver communication. Although these requirements are not claimed to be exhaustive, they indicate a desire for organizational and technological integration of people as well as the systems they use.

However, as is evident from our study, well-functioning best-of-breed mobile–stationary assemblages are difficult to accomplish. In the quest for a total solution to the service requirements of road haulage firms, specific challenges concern the integration of people, distributed heterogeneous mobile and embedded technologies, and stationary transport business systems. Typically, stationary office systems increasingly target mobile resources (drivers and vehicles), thus extending their reach. Correspondingly, mobile systems target the stationary part of the organization, offering opportunities for surveillance and evaluation. As highlighted by our respondents, however, road haulage firms were unwilling to embrace mobile system vendors' solutions for both mobile and stationary parts. Instead, they had to seek assemblages of mobile and stationary systems originating from very dissimilar sources. As a result, services offered by mobile and stationary system vendors were typically implemented in parallel rather than integrated. In effect, the organizations included in our study were at best marginally successful in their attempts to integrate mobile and stationary people and systems into a seamless computing environment.

5.2 Overcoming the Mobile–Stationary Divide

Despite these negative experiences, attributing to technology the ability to seamlessly interconnect various technological and social elements, respondents in several of the organizations were determined to overcome what they experienced as a mobile–stationary divide. In what follows, we highlight challenges surrounding mobile–stationary assemblages that transport organizations must tackle in efforts to efficiently use existing transport business systems while adding mobile technologies that exploit additional opportunities. Indeed, we believe our lessons learned from the transport industry are applicable also to general infrastructure challenges in ubiquitous computing environments.

Because road haulage firms are constituted mainly of a distributed and constantly moving workforce, they are well aware of the potential opportunities residing in technology support for mobile resource evaluation. Such technology support is receiving much attention from system vendors, and commercial service packages are available. Although beneficial for dispatchers and management, to monitor the digital traces of distributed working activities in this way raises the delicate issue of supervision on behalf of the drivers. Indeed, our study indicates a concern among road haulage firms about the potential effect on drivers' attitudes toward system support and their organizational commitment. This dual nature of ubiquitous technologies on one hand supporting work processes and on the other hand facilitating surveillance of employees is a topic previously addressed by, for example, Jessup and Robey (2002).

Furthermore, designed to bridge the gap of geographical dispersion and mobility, sophisticated embedded vehicle sensor networks make sources of potential knowledge available for road haulage firms. More specifically, formalized assignment processing within the confines of an integrated computational solution, combined with automated instant retrieval of vehicle performance data, facilitated by wireless communication ensure constantly updated sources of timely information. In filtering and combining these sources of information lies the potential of increased understanding of the organization (Jessup and Robey, 2002). However, arguing that an acceptable representation model of field activity is heavily dependent on the specifics of the various environments, several managers considered simplified context parameters to be of limited use. Furthermore, the perceived need for interaction between mobile and stationary actors highlights the situated character of context creation in organizational settings.

Indeed, in the attempts to achieve a mutual understanding of the context of everyday actions in organizations reveal that the nature of context and its encoding are challenging questions (Dourish, 2004). Hosting a combination of stationary, mobile, and pervasive applications, ubiquitous computing architectures potentially grant stationary actors detailed digital traces of mobile work; not only through positioning technology, but also via embedded sensor networks and similar technologies. The interpretation of this newfound organizational context awareness is far from obvious, considering the difference in work practice between mobile and stationary actors. Our first managerial implication is thus, that the meaning and use of new context information will have to be negotiated in organizations.

A significant reason for road haulage firms to invest in technology support is the promise of improved efficiency by automation, facilitating seamless processes throughout the organization. The rationale behind most enterprise-wide infrastructure implementations is to eliminate manual keying of data from one system to another. As our study verifies, recent technological advances have brought such promises also to highly mobile transport organizations. In the road haulage context, there are high expectations of new services promoted to greatly reduce the human effort in dispatching, invoicing, and auditing by ensuring an unbroken and streamlined flow of information throughout a cross-functional, geographically dispersed process. The great potential of technology as facilitator of seamless transport data propagation (by automating presently manual tasks) was a topic highlighted by many respondents. However, existing problems associated with the integration of mobile in-vehicle telecommunication services for order management and stationary transport order systems in the office were seen as a major barrier. Consequently, as asserted by several managers, the vision of an uninterrupted flow of transport data between mobile and stationary actors was at best only partly realized in the present situation. Analogous to most distributed computing environments, a critical factor was the diversity of data and information formats used (March et al., 2000).

In the current situation, several unresolved technical issues exist regarding the development of UTS with the capacity to meet the service requirements of transport firms. Geographically dispersed ubiquitous computing architectures for transport organizations will be technically complex in terms of the number of portable devices, embedded applications, databases, and systems involved, requiring a common platform of protocols and data standards to ensure systems interoperability and enable the integration of a plethora of distributed technologies. As our study indicates, this situation can be traced to rivalry and competition between various technological solutions, originating from diverse innovation regimes (Godoe, 2000). Merging mobile and ubiquitous computing with stationary business computing will thus pose specific challenges. Our second managerial implication is that organizations migrating to ubiquitous computing environments will not be able to manage the increased system heterogeneity without a supportive infrastructure and a sound organizational strategy. In particular, this requires an understanding of knowledge bases of mobile and stationary system vendors and the interactions between these actor groups.

Whereas verbal communication related to transmission of transport order data can be minimized, gathering of vital information can be performed without any form of human interaction (e.g., real-time positioning of vehicles), thus increasing efficiency. Our study shows that, compared to the telephone, alternative forms of communication technology such as in-vehicle support for message handling, although viewed as efficient, were also perceived as inflexible and limited to the confines of the organization. This finding suggests that workers in highly mobile environments may need to use older technologies (such as telephones) to complement their dependence on distributed message-based communication services (Jessup and Robey, 2002). Furthermore, managers in road haulage firms seem to focus primarily on the positive impact on stationary actors' (e.g., dispatchers) work situation when considering the effects of improved efficiency. It goes without saying that this trade off between efficiency and flexibility also entails social issues. The flexibility of verbal communication offers opportunities for spontaneous communication. Minimizing the need for instances of verbal communication is likely to reduce these opportunities. In a longitudinal study, Sarbaugh-Thompson and Feldman (1998) noticed tendencies of less organizational commitment in the long run resulting from electronic communication within an organization. This suggests that casual conversations facilitate organizational activity by establishing or maintaining relationships between dispersed fellow workers. In the context of transport organizations, increasing efficiency by reducing verbal communication may reinforce the solitary nature of drivers' work. In terms of attempts to integrate social and technological elements in distributed environments, this indicates a delicate balancing act of fostering efficiency while maintaining sufficient flexibility.

In attempts to deploy computer-mediated communication, transport organizations must investigate how mobile and stationary actors use electronic media in formulating and engaging in social action. In addition, they must also identify what types of electronic media enable and constrain specific types of action (Ngwenyama and Lee, 1997). As suggested by our empirical study, the combined efforts of mobile and stationary work require flexible communication technology. Social complexity and flexibility is found on one end of the scale ending in augmented organizational efficiency. To be able to provide opportunities for flexible and rich communication in mobile–stationary assemblages, while rationalizing mobile–stationary communication, our third managerial implication is that organizations must consider a multiplicity of interaction media. Table 1 summarizes the service requirements, infrastructure capabilities, and core managerial implications identified in this research.

Service requirements	*Infrastructure capabilities*	*Managerial implications*
Improve mobile resource evaluation	Context awareness	Negotiation of context
Facilitate seamless transport data management	System heterogeneity	Strategy for handling diverse innovation regimes
Rationalize dispatcher-driver communication	Communication flexibility	Balance media multiplicity

Table 1: Service requirements, infrastructure capabilities, and managerial implications

6 CONCLUSION

In this article, we use the term UTS to discuss seamlessly integrated computing environments applicable to the transport industry. The article reports expectations and experiences of UTS in Swedish road haulage firms. A central issue in the quest for a total solution to the service requirements of road haulage firms is the mobile–stationary divide. We refer to the mobile–stationary divide as a set of challenges associated with integration of mobile and stationary people and systems into a seamless computing environment. Our lessons learned apply also to other ubiquitous computing environments that depend on the successful integration of both mobile and stationary technological and social elements.

Addressing general infrastructure challenges in ubiquitous computing environments, this article contributes explicit managerial implications for organizations attempting to integrate mobile and stationary information systems. The three managerial implications identified and discussed in the article are as follows: (1) the meaning and use of new context information will have to be negotiated among organizational stakeholders; (2) organizations migrating to ubiquitous computing environments will not be able to manage the increased system heterogeneity without a sound organizational strategy; and (3) the integration of mobile and stationary communication requires that organizational members have a multiplicity of interaction media available to them.

Organizations should not blindly rush into ubiquitous technologies. We recommend that managers first try to understand their business and needs for ubiquitous computing support, but they must not forget about the multifaceted challenges likely to surround attempts to integrate traditional business and mobile computing with pervasive computing functionality into ubiquitous computing architectures. Finally, further IS research is imperative to comprehend the challenges reported in this article. We encourage detailed studies of attempts to bridge the mobile–stationary divide by developing supportive infrastructures (involving heterogeneous, geographically distributed computing resources) that span far beyond the stationary parts of organizations. IS researchers are encouraged to study organizational consequences caused by the complexity created by such attempts to integrate both mobile and stationary technological and social elements into distributed architectures. Equally important is the need for studies addressing the changes in social action that the development of such ubiquitous computing environments is likely to render.

7 APPENDIX

The primary data collection method was a series of interviews with key personnel in 12 road haulage firms in the fall of 2002 (see Table 2). The Swedish Road Haulage Association, representing approximately 11,000 road haulers with approximately 30,000 vehicles and machines, recommended a number of potentially interesting member road haulage firms. These organizations used IT support as a means for improved business performance, but they were diverse in terms of core business, structure, external relations, and size. This diversity was beneficial in view of our attempt to understand the situation experienced by road haulage firms in general. Examining potential similarities and differences between organizations, we chose to interview influential individuals in leading managerial positions (business and technology managers). Due to the limited size and complexity of small- and medium-sized firms, managers are usually involved in every organizational process and tend to have a comprehensive perspective of organizational issues (Caldeira and Ward, 2002). Besides the managerial perspective of the interviewees, most of these individuals also had previous personal experience as truck drivers or dispatchers, thus providing interesting information on these roles as well.

Intricate organizational interdependencies with substantial situational variations can be hard to identify using formal data collection methods (Walsham, 1995). Therefore, to acquire a rich picture of the actions and processes in the organizations, we used semi structured interviews, lasting between one and two hours, as the primary method of data collection. This technique can illuminate potential particularities of the individual organizational settings, by allowing forming and reforming of alternative questions as well as detailed explanations and interesting detours whenever necessary (Walsham, 1995). However, some structure is retained so that there is satisfactory correlation between the different interviews. The interview sessions were focused on the perceptions of technology in relation to seamless integration of diverse technologies, distribution of contextual awareness throughout the organization, and communication.

The interviews were recorded and later transcribed. During the analysis, the data was first examined for statements reflecting the respondents' expectations and experiences of technology support and its implications for work and their organization's processes. After this, we approached the data with an open mind, meaning that the data itself suggested concepts and categories. The concepts and categories were revised and refined until they sufficiently explained as much of the data as possible. Our empirical findings can thus be said to have emerged from an iterative and interpretive analysis of the collected data (Walsham, 1995).

In addition to our empirical efforts to capture experiences and expectations of enterprise-wide support in the context of the road haulage business, we also conducted an IS literature review to search for research contributions addressing enterprise architectures in highly mobile organizations. This review included top IS conferences and journals and covered the period between 1990 and 2004. Although our review indicated the scarcity of research efforts focusing on this topic, recent literature on challenges in heterogeneous and distributed computing environments has served as useful input in our quest to understand infrastructure capabilities of UTS.

Case	***Respondent***	***Ownership***	***Size***	***Business & regional coverage***	***IT support***
A	Managing Director	Independent	35 vehicles 40 employees	• Recycling, waste disposal, some local 'less-than-truckload' (LTL), and mobile construction equipment	• Stand alone transport management system • Searching for new management system with integrated mobile support
B	Managing Director	Contractor dependant (Schenker)	45 vehicles 50 employees	• Regional distribution	• Local access to web-based order system with contractor • Dispatcher on-site at contractor terminal with integrated transport management system • Basic credit-invoicing control system. • Only one Mobitex-based mobile system. • Awaits contractor or haulage association IT initiatives
C	Managing Director	Independent	15 vehicles	• Sea container goods (LTL) • Operates in	• Largely spreadsheet based planning • Mobitex-fax in one vehicle

			25 trailers 30 employees	Nordic countries and Portugal • Manages a small terminal • Assignments from local contractor (DFDS) plus direct customers • Direct invoicing	• Awaits others' initiative and contractor demands
D	Managing Director	Contractor dependant (Danzas)	71 vehicles 85 employees	• Distribution and parcel delivery	• Transport management system • Vehicles equipped with bar code scanners integrated with contractor's systems • Mobitex-based mobile messaging system developed by contractor. • Stand alone maintenance/ environmental system • Reacts on contractor demands and initiatives
E	Account manager	Independent	20 vehicles 25 employees	• Chemical transports for one customer • Operates in Scandinavia plus some continental transports • Credit invoicing	• In-house developed stand alone planning system • New in-vehicle computers in long distance vehicles • Webb access to costumer stock levels • Reacts on costumer IT demands
F	Managing Director	Independent	60 vehicles 70 employees	• Parcel delivery	• Limited use of transport management system for pricing and invoicing (integrated with pricing and invoicing systems)
G	Managing Director	Independent	15 vehicles 30 employees	• Mover • Member of a road hauler network	• Stand alone transport management system • Simple web-based costumer system
H	Managing Director	Independent	26 vehicles 30 employees	• Waste distribution, construction bulk, and parcel delivery (single customer) • Manages small terminal • Credit invoicing from contractor of waste distribution	• Limited use of IT-support (automatic fuelling system) • Previously sported vehicle Mobitex systems sponsored by parcel customer, now withdrawn • Reacts to customer demands
I	Site manager	Alliance with French postal	3000 employees in 7	• Distribution (pallets and parcel)	• Previous use of Mobitex units replaced by mobile phones

		services to expand range	national regions Local unit: 45 vehicles 75 employees	• Manages a terminal • Credit invoicing	• Drivers equipped with handheld devices for barcode scanning for track and trace purposes. • Little or no managerial drill down support • Order management system integrated with main organization • IT support for route calculation and pricing
J	Managing Director	Member of a local independent hauler association	12 vehicles 15 employees	• Metal transports and recycle material • Regional • Long term contracts	• A few vehicles equipped with Mobitex units • Manually fed fuel and time control systems • No drill down capabilities • Reactive stance to new IT investments
K	Account manager	Contractor dependant (Schenker)	100 vehicles 145 employees	• Regional distribution	• Transport management system integrated with contractor since 1993 • Mobile communication of assignments since 1995 (Mobitex-based), currently SMS-based, but legacy remains in use (radio, old Applicom units) • Credit invoicing control system (partly web-based) • Invests in response to contractor demands • Involved in a national road haulage association IT group • Transport system is a joint venture of contractor and hauler association
L	Transport manager	Part of an international organization	70 vehicles 100 employees	• Household and industry waste disposal • Manages waste handling sites	• Mobitex printers in vehicles, connected to vehicle scales • Mobile handheld units for barcode scanning of bins and deviation reporting • In house spreadsheet application for maintenance (fed by information from brand maintenance workshops)

Table A.1: Case descriptions

8 REFERENCES

Akinci, B., C. Hendrickson, and I. Karaesmen (2003). Exploiting Motor Vehicle Information and Communications Technology for Transportation Engineering. Journal *of Transportation Engineering*, 129 (5): 469–474.

Angeles, R. (2005). RFID Technologies: Supply Chain Applications and Implementation Issues. *Information Systems Management*, 22 (1): 51–65.

Banavar, G. and A. Bernstein (2002). Software Infrastructure and Design Challenges for Ubiquitous Computing Applications. *Communications of the ACM*, 45 (12): 92–96.

Caldeira, M. M. and J.M. Ward (2002). Understanding the Successful Adoption and Use of IS/IT in SMEs: An Explanation from Portuguese Manufacturing Industries. *Information Systems Journal*, 12: 12 1–152.

Davenport, T. H. (1998). Putting the Enterprise into the Enterprise System. *Harvard Business Review*. July–August: 121–131.

Dey, A.K, G.D. Abowd, and D. Salber (2001). A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications. *Human–Computer Interaction*, 16: 97–166.

Dourish, P. (2004). What We Talk about When We Talk about Context. *Personal Ubiquitous Computing*, 8: 19–30.

Giannopoulos, G.A. (2004). The Application of Information and Communication Technologies in Transport. *European Journal of Operational Research*, 152(2): 302–320.

Godoe, H. (2000). Innovation Regimes, R & D and Radical Innovations in Telecommunications. *Research Policy*, 29: 1033–1046.

Jessup, L.M. and D. Robey (2002). The Relevance of Social Issues in Ubiquitous Computing Environments. *Communications of the ACM*, 45(12): 88–91.

Lee, J., K. Siau, and S. Hong (2003). Enterprise Integration with ERP and EAI. *Communications of the ACM*, 46(2): 54–60.

Luff, P. and C. Heath (1998). Mobility in Collaboration. *In Proceedings of CSCW — 1998*: pp. 305–3 14.

Lyytinen, K. and Y. Yoo (2002a). Research Commentary: The Next Wave of Nomadic Computing. *Information Systems Research*, 13(4): 377–388.

Lyytinen, K. and Y. Yoo (2002b). Issues and Challenges in Ubiquitous Computing. *Communications of the ACM*, 45(12): 63–65.

March, S., A. Hevner and S. Ram (2000). Research Commentary: An Agenda for Information Technology Research in Heterogeneous and Distributed Environments. *Information Systems Research*, 11(4): 327–341.

Markus, M.L. and C. Tanis (2000). The Enterprise System Experience: From Adoption to Success. In Zmud, R.W. (ed.) Framing the Domains ofIT Research: Glimpsing the Future through the Past, *Pinaflex Educational Resources,* Cincinnati: 173–207.

Ngwenyama, O.K.Lee, A.S. "Communication Richness in Electronic Mail: Critical Social Theory and the Contextuality of Meaning," *MIS Quartely* (21:2) 1997, pp 145-167.

Roy, J. (2001). Recent Trends in Logistics and the Need for Real-Time Decision Tools in the Trucking Industry. *In Proceedings of the 34th Hawaii International Conference on System Sciences.*

Sambamurthy, V. and R. Zmud (2000). Research Commentary: The Organizing Logic for an Enterprise's IT Activities in the Digital Era — A Prognosis of Practice and a Call for Research. *Information Systems Research*, 11(2):105–114.

Sarbaugh-Thompson, M. and M.S. Feldman (1998). Electronic Mail and Organizational Communication: Does Saying "Hi" Really Matter? *Organization Science,* 9(6): 685–699.

Shang, S. and P.B. Seddon (2002). Assessing and Managing the Benefits of Enterprise Systems: The Business Manager's Perspective. *Information Systems Journal*, 12: 271–299.

Walsham, G. (1995). Interpretative Case Studies in IS Research: Nature and Method. *European Journal of Information Systems*, 4(1): 74–81.

Williams, M.L. and M.N. Frolick (2001). The Evolution of EDI for Competitive Advantage: The FedEx Case. *Information Systems Management*, 18(2): 47–53.

SECOND PAPER

2 ENACTING UBIQUITOUS COMPUTING ENVIRONMENTS

A PRACTICE LENS ANALYSIS

MAGNUS ANDERSSON

ABSTRACT

In recent years, IS researchers have started to explore issues surrounding implementation and use of integrated information technology. Given that ubiquitous computing environments are becoming integral to organizational processes in a wide number of industries, the integration of previously divided technologies is indeed a worthwhile subject of study. However, there are few studies that specifically investigate how user organizations adopt assemblages of services and devices across organizational contexts. Targeting this gap, this paper explores how constant availability of information in multiple social and physical contexts impacts organizational practices in integrated information environments. A multiple-case study of transport organizations combining embedded, mobile, and stationary technologies is analyzed utilizing a practice lens perspective. The analysis of enactments of ubiquitous computing environments revealed both intended and unintended outcomes were found. Reflecting on the contradictory outcomes identified, the paper makes two important contributions. First, it conceptualizes organizational implications of integration of heterogeneous technologies. Second, it extends the current understanding of how to study interplay between agency, structure, and technology in tomorrow's assemblages of advanced technology.

1 INTRODUCTION

For some time the relationship between organizations and various forms of integrated information technologies have been illuminated by IS research, including multifunctional enterprise wide systems (cf. Boudreau and Robey 2005; Pozzebon 2001; Sia et al. 2002). Increasingly, the same could be argued when discussing mobile (Cousins and Robey 2005; Sørensen and Pica 2005) or embedded technology (Henfridsson and Lindgren 2005; Jonsson and Holmström 2005). However, there is limited knowledge of how integrated information environments comprising of all of the above mentioned classes of technology are used in organizations. Indeed, Lyytinen and Yoo note that IS research has been more interested in "…discrete applications or technologies, not in complex environments that enable organizations to mobilize information and its sharing" (Lyytinen and Yoo 2002b). As previously separated technologies are becoming increasingly intertwined in everyday work, this is an omission that needs to be addressed. This emerging phenomenon is increasingly discussed in the IS community using the term "ubiquitous computing" (Jessup and Robey 2002; Lyytinen and Yoo 2002a).

Ubiquitous computing environments (UCE) entailing a multitude of separately designed but increasingly networked technologies are an increasingly integral part of organizational processes in a wide number of industries (Akinci et al. 2003; Angeles 2005; Jonsson and Holmström 2005). Indeed, there is a need to shift focus from understanding how a single user adopts and exploits a specific application or technology to understanding how users adopt, varying sets of services on various devices across multiple organizational contexts (Lyytinen and Yoo 2002b). As noted by Jessup and Robey (2002), it is only when engaged by social actors that actual consequences will occur. It is therefore crucial to identify and study empirical settings in which information technology from different domains are present and utilized in an integrated fashion (Lyytinen and Yoo 2002a). In this vein, this paper addresses the following research question: *How does the constant availability of information in multiple social and physical contexts impact users and organizations in integrated information environments?* The paper draws on an analytical practice lens (Orlikowski 2000) to explore organizational utilization of integrated mobile, embedded, and stationary information technologies. A practice lens is well suited for studying this type of phenomenon because it acknowledges technology, human agency, and social structure concurrently. Thus, the goal of utilizing a practice lens perspective is to elicit enactments of technology bridging divides of discrete technologies and routines. Prior research has shown that the transport setting is a promising empirical venue for studying such issues (Andersson and

Lindgren 2005). Analyzing a multiple-case study of UCEs consisting of embedded vehicle systems, mobile devices, and stationary business systems, this paper identifies a set of technology enactments where coexisting mobile and stationary contexts are central to organizational performance. In doing so it contributes to the emerging IS ubiquitous computing literature a conceptualization of organizational implications of integrating heterogeneous technologies. Furthermore, it extends the current understanding of how to study interplay between agency, structure, and technology in tomorrow's assemblages of advanced technology.

This paper is organized as follows. An introduction to UCE and its application is followed by an explanation of the practice lens applied. Proceeding, the case selection and method of analysis are described. Empirical accounts of enactments of UCE are then presented. Finally, the results are discussed and concluding remarks suggesting opportunities for future research are developed.

2 Ubiquitous Computing Environments

A popular vision throughout the nineties was that of the white collar knowledge worker roaming the digital jungle accessing anything from just about anywhere at any time. Mobile technology is being networked with stationary business information technology (Cousins and Robey 2005). Furthermore, information technology embedded in physical surroundings is rapidly changing a growing number of practices and enabling new ones. Indeed, the added inclusion of physically embedded technology is changing the way people interact with and through technology as traditional information systems become integrated with mobile and embedded technologies such as RFID and various sensor technologies (Lyytinen and Yoo 2005).

One central issue in developing integrated environments consisting of stationary, mobile and embedded information technologies, and using them in organizations is to handle their inherent heterogeneity. These UCEs can be seen as networked components of stationary, mobile, and embedded information technology (Lyytinen and Yoo 2002a). Such environments entail a multiplicity not only of technologies, but also of actor roles and organizations. Implementing organizations face organizational, social, as well as technological challenges (Lyytinen and Yoo 2002b). At the organizational level, there are challenges related to the managerial rationale for designing and evolving their IT activities in response to the imperatives of changing business and technological environments that need to be tackled (cf. Sambamurthy and Zmud 2000). Indeed, there are indications that the organizing logic must be adapted to an assemblage of interconnected social and technical elements. Moreover, this process of adapting to interweaving technologies promises to involve redefinitions of social action as well as new social behavior (Jessup and Robey 2002).

Given the wide heterogeneity of technologies involved the extant scope of the term “integrated” can be seen as narrow for such environments as it usually refers to a selection of features of stationary computerized information systems. As an example, Boudreau and Robey (2005) view enterprise resource planning (ERP) systems as such an instantiation of integrated information technology (information system with multiple functions and users). They contrast ERP with Orlikowski’s (1996) user malleable CASE technology that is less coupled or integrated. In this paper, the notion of integration notion is applied slightly differently due to the widely differing sets of technologies involved. However, a UCE bears clear similarities to the conventional characteristics of integrated information technology. First, similar to what has been repeatedly reported on monolithic ERP systems, a UCE is not easily transformed in its physical shape once in place. Second, it is clearly distinctly multi-functional as mobile and stationary users perform different tasks through it. In addition, by connecting and supporting geographically dispersed actors it is tightly coupled to the work context. However, at the same time, a UCE holds some characteristics that clearly set it aside from conventional information systems. Most importantly, a UCE seems to be far more multifaceted considering its diverse component technologies. Various actors interact with different constituent technologies or components, some of which appear tightly coupled technically as well as organizationally, whereas others do not.

Jonsson et al. (2004) describe a maritime setting where onshore stationary personnel interact with and through co-located stationary components that are integrated with embedded field technology in turn utilized by off shore operational control personnel. In this particular scenario, the existing embedded technology is a remote diagnostics system within the ship’s crane being utilized to create novel services spanning multiple contexts of use. As another example, the transport industry has for some time been exposed to UCEs. There, two broad categories of technologies can be distinguished (Andersson and Lindgren 2005). The first relates to the mobile side of transport organizations, that is, the information technologies permeating the vehicles used by drivers in daily work practice. These include both vehicle systems (e.g., embedded vehicle sensor systems) and driver-centric information technology (e.g., in-vehicle services for order management and message handling). The second relates to the stationary side of transport organizations, that is, the set of office systems associated with controlling and coordinating transport assignments and mobile resources. These include systems for fleet wide transport order management and cargo planning, resource coordination, and route calculation.

These examples are clear indications that through technology embedded in physical surroundings or of portable design, new kinds of work contexts are becoming intertwined with those traditionally associated with information systems thereby expanding their reach.

Integrated technology such as ERP, is designed to cater for processes involving multiple functions and people in a uniform manner, while single user applications have been conceptualized as more easily adapted in use (Boudreau and Robey 2005). UCEs, in turn, could be seen as reminiscent of both in that they entail a multitude of separately designed but increasingly networked technologies. For instance, the UCEs depicted in Jonsson et al. (2004) and Andersson and Lindgren (2005) include multiple linkages. These connect stationary work contexts and their associated technological environments as well as a mobile work context and its associated environment of mobile and embedded technologies. These links include both human communication and direct machine readings. A significant driver for UCE implementation is the possibility to integrate stationary business systems directly to technology embedded in physical goods, thereby avoiding costly human interpretation and input (Müller and Zimmermann 2003). However, the interplay of links between on the one hand embedded technology and stationary business systems, and on the other the links between humans conferred by mobile technology components is largely unexplored. UCEs should both provide awareness of the status of mobile stationary boundary spanning activities and offer features which help dispersed actors coordinate their activities and share ideas across temporal and spatial boundaries. Indeed, the impact of UCE can be assessed both in terms of performance and development (Lyytinen and Yoo 2002b).

Prior research indicate that alignment of mobile, embedded, and stationary technologies can be difficult to achieve (Andersson and Lindgren 2005; Jonsson and Holmström 2005). This paper explores associated challenges further by explaining the relations between multiple users separated through space and time interacting with and through heterogeneous technologies in a road transport industry setting.

3 ENACTING TECHNOLOGY

The theorizing of interplay between social actors and information technology in IS is continually evolving. One of the most central aspects of this development is a growing rejection of technology determinist viewpoints (Barley 1986; Orlikowski 1992), that a given technology regardless of context causes certain consequences by just being implemented into an organization. Consequently, social structures in the organizational context of information technology in use have gained considerable interests from IS scholars. While the importance of social context has been introduced successfully, mirroring debates in sociology additional critique has pointed to the treatment of such social structures as an independent variable or a stable phenomenon. In this sense, social structure is supposedly restricting individuals who are essentially incapable of actions opposing them (Orlikowski and Robey 1991; Walsham 1993). Acknowledging the capacity of knowledgeable individuals to act in correlation with as well as opposing a given structure, structuration theory (Giddens 1984) views the relationship between structure and agency as interwoven. In this way, agency can be seen as continually influencing and being influenced by structures through specific modalities. As such, the structures themselves are purely virtual and exist as traces in the mind observable only through patterns of human action. However, being a general theory of social organization, it has been noted that structuration theory has not specifically dealt with technology. For this reason it has been adapted by the IS community and used in specific forms. Two notable such forms are adaptive structuration (DeSanctis and Scott Poole 1994) and practice lens (Orlikowski 2000).

Criticizing the dichotomous view of duality of technology as objective or socially constructed, Orlikowski (2000) use structuration to elicit a “practice lens” through which people can be

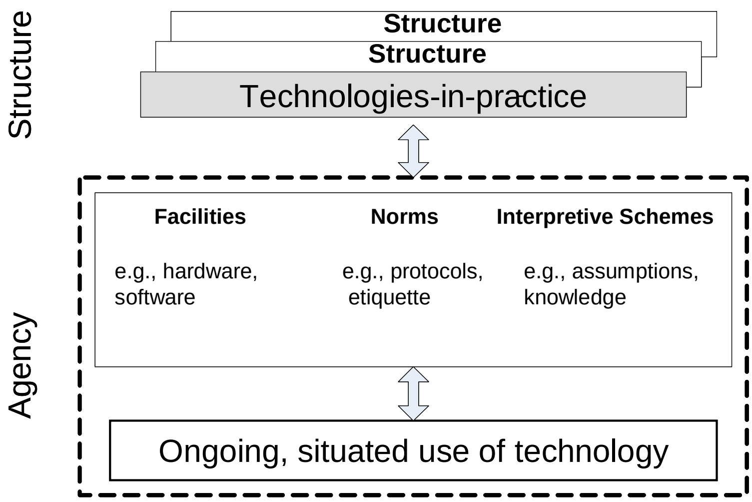

Figure 2: Orlkowski's (2000) practice lens model

observed enacting structures in interacting with technology, in turn shaping their emergent use of that technology and the technology itself. In this sense, people interact with some or all of the material and symbol properties of technology, enacting a *technology-in-use* rather than merely responding to structures embedded within it. Technology can thus be seen to both constrain and enable the ongoing processes of structuring within organizations. A practice lens perspective enables shedding light on the interplay between individuals, technology, and structure. In moving between the micro level of individual enactment of technology and the macro level of social structures in an organization, the often unintended consequences of information technology use can be better understood. Examples of such phenomena are that expected consequences do not occur, that different consequences result from the use of nearly identical technologies in comparable settings, or that contradictory consequences result from the same technology in a single organization (Robey and Boudreau 1999).

While human agency and a social construction of technology is at the heart of the practice lens as proposed by Orlikowski, the physical properties of technology are by no means treated as irrelevant. As indicated by Orlikowski (2000) and more specifically addressed by Boudreau and Robey (2005), not all technologies are equally malleable and hence will potentially constrain or enable human agency in organizations in different ways and to different degrees. Viewing enterprise resource planning (ERP) systems as an integrated technology through which work and workers are tightly coupled, hence suggesting rigid patterns of action that are hard to circumvent, Boudreau and Robey illustrate the capacity of individuals to nonetheless resist and reinvent technology in enactment. While this is an important insight, UCEs are potentially far more heterogeneous in terms of involved technologies as well as physical and functional reach. It is unclear how the integration of mobile, embedded and stationary systems will impact individuals and organizations alike (Lyytinen and Yoo 2002b). Indeed, as suggested by Orlikowski (2000), the increased malleability conferred by user configurable applications and the decreased malleability conferred by the increased interconnectivity and interdependence may act as opposing forces. The former would thus enable users to freely interpret and appropriate it while the latter would enforce existing structural patterns. The focal object of technology in the guise of UCE is an integrated assemblage of heterogeneous components. The specific components interacted with could therefore vary from actor to actor within an organization. There is reason to believe that this networked view of technology will influence how agency and structure plays out. Agency will involve common structures spanning multiple contexts distributed both spatially and temporally through heterogeneous technologies. In such environments, the unintended will most likely blend with intended outcomes of technology implementation in partly novel ways. To capture such phenomena, it will be necessary to study the spanning of boundaries of multiple practices in connected contexts. By utilizing a practice lens the analytical foci of agency, technology, and structure can shed light on these matters.

4 RESEARCH METHOD

4.1 RESEARCH DESIGN AND SITES

As mentioned, one of the merits of a practice lens is its capacity to elucidate differentiating outcomes of using similar technologies in comparable settings (Robey and Boudreau 1999). In line with this reasoning, this research was designed as a multiple-case study, covering organizations that try to bridge the divide between mobile and stationary practices by implementing UCEs. Such integrated information environments are especially attractive to organizations where coordination of diverse sets of mobile units is central to organizational performance, such as transport organizations. For example, the typical road haulage firm coordinates a workforce mainly consisting of drivers who are geographically distributed and constantly moving, providing timely pickup and delivery of goods.

Plagued by low margins and intensive competition, road haulage firms have implemented a wide variety of distributed IT support tools to conduct their day-to-day business (Andersson and Lindgren 2005). Such IT support includes services that offer dispatchers overviews of their mobile resources by positioning individual trucks, drivers route calculation services to minimize time and fuel expenditures of assignments, and managers vehicle performance recording services for accurately following the mobile workflow (cf. Akinci et al. 2003; Giannopoulos 2004; Roy 2001). As depicted in Figure 3, a UCE contains both the context signals from the embedded systems and the mobile-stationary communications between the actors of the organizations different contexts. This setting is thus characterized by stationary, mobile, and embedded information technology coupled to diverse use contexts. This makes the road transport industry an ideal research setting in which to study how constant information availability over multiple social and physical contexts will impact users and organizations coupled by a UCE.

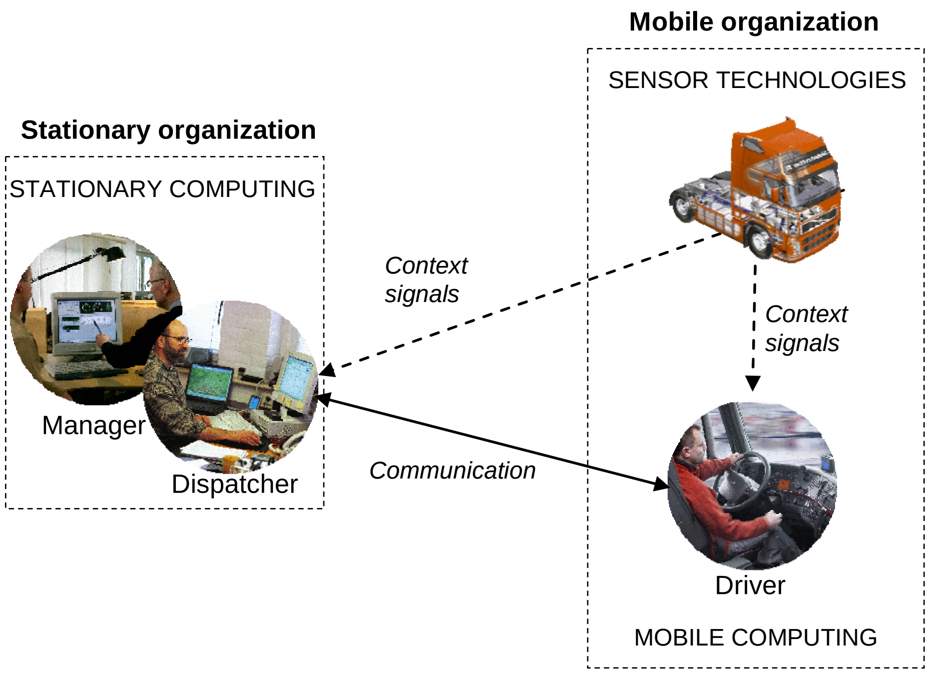

Figure 3: A road transport UCE

In order to acquire a sample of cases, six information system vendors were approached for recommendations of user organizations of interest. These vendors recommended customer cases that had implemented an organizational UCE. From this process, six cases were selected to be included in the study (see Table 1). However, after a more thorough examination of these six cases, only four had experience pertaining to an implemented environment consisting of embedded and mobile as well as stationary technologies. This paper therefore contains empirical material from these four cases.

Organization	*Size*	*Ownership*	*Systems* *Mobile*	*Stationary*	*Transports*
A	325	Independent	CoDriver	SAdata	Bulk, foods, oil, goods
B	300	Co-op	Barkfors	TDXlog	Goods
C	100	Independent	Dynafleet	Transport 2000	Foods, goods
D	40	Independent	FAS	In-house system	Foods, goods

Table 3. Case Overview

The distinct collection of features found within the computing environments of the cases concerned services dedicated to support daily work practice. As previously mentioned, these highly specialized integrated environments consisted of a number of discrete components originating from vendors focusing on embedded, mobile or stationary technologies respectively. A summary of these features can be found in table 2.

Feature	*Summary*
Vehicle data	Displays data from embedded vehicle systems, primarily concerning fuel consumption, through the CAN-bus interface to drivers and managers via mobile or stationary hardware and applications.
Fleet positioning	Relays GPS-enabled information on fleet vehicles' position to dispatchers' digital map interface.
Text messaging	Allows unstructured textual messaging between drivers and dispatchers
Mobile order management	Allows transmission of structured assignment information between stationary and mobile actors
Stationary order management	Support for resource allocation and task monitoring

Table 4. Feature summary

The distribution of these features among the cases showed some heterogeneity, as shown in table 3. Most notably, all cases included both stationary and mobile order management features as well as text messaging features. All of them had access to either vehicle data or positioning features. Half of the cases utilized both. The relative difficulty in getting access to cases containing fully implemented embedded technology was indicative to the relative scarcity of mobile and embedded technology in use. Indeed, depending on region, as few as below 1 percent or at the most 7 percent of the vehicles of European commercial fleets are equipped with such technology (Ryberg 2006).

Case	*Vehicle data*	*Fleet positioning*	*Text messaging*	*Mobile order management*	*Stationary order management.*
A	X		X	X	X
B		X	X	X	X
C	X	X	X	X	X
D	X	X	X	X	X

Table 5. Case feature distribution

A major structural difference found among the cases concerned the level of autonomy of the mobile actors. Two forms of organizing were evident. The first was a traditional arrangement in which the company owned the mobile resources and paid regular wages to employed drivers. The second was a collaborative environment in which a number of separate road haulers jointly owned the stationary part of the organization. This part was responsible for the daily allocation of available tasks to the independent haulers. However, the practical everyday tasks to be performed by drivers and dispatchers were found identical in these two types of organizations.

4.2 DATA COLLECTION AND ANALYSIS

This study builds on 6 sources of empirical data. These are interviews with system users, documents produced by users in daily practice, notes from user observations, system vendor documentation, and observation notes from vendor demonstrations. To cover experiences of technology use, individuals involved in three different types of work (dispatchers, drivers, and managers) were interviewed in each of the four organizations. Questions concerned experiences of user's interaction with technology and social effects on work practice. The resulting 12 semi-structured interviews lasting between 1 and 2 hours were recorded and later transcribed to facilitate analysis. While these interviews provide the bulk of the empirical data, supplementary data was also gathered. To address ambiguity emerging in these interviews, observations of systems in use were made whenever needed. For example, a driver using an in-vehicle order management system would be observed en route in an everyday work setting and field notes taken. These were subsequently compared to the statements given to guide the analysis. Attention was given to the current practices as well as the historical context and actors were encouraged to provide their accounts of their work preceding the implementation of an UCE.

A practice lens can be applied utilizing diverse analytic approaches. As a structuration perspective can be seen as a meta-theory (Orlikowski and Robey 1991), it guides the research by focusing attention to generic issues such as the intended and unintended consequences of technology implementation. While it provides little insights into specific phenomena, it does not preclude the utilization of more specific theory (cf. Schultze and Orlikowski 2004). Likewise it has been utilized in research of a theoretically influenced grounded theory character (Strauss and Corbin 1990). An example of the latter is Boudreau and Robey (2005).

This work was directed to challenges associated with the multiplicity of use contexts inherent in UCEs. As such it was therefore not conceived or performed without previous knowledge of the field. Analyzing the material, reoccurring patterns of use were elicited from all cases along with traces of organizational structures invoked or challenged through the use of the UCE. While not explicitly following the grounded theory approach (Strauss and Corbin 1990), the overall process exhibits similarities. The research was conducted in an open-ended manner. In accordance with the selective coding technique (Strauss and Corbin 1990), the elicitation of commonalities of technology-in-use was performed by moving between empirical data and previous research on ubiquitous computing and information technology agency iteratively and concepts were discovered, defined, and refined throughout the research. This procedure lasted until no further technologies-in-use were emerging.

5 Findings

This section outlines three key instances of technology-in-use evident in the case organizations. They all concern everyday activities spanning the mobile-stationary boundary of the organization in which multiple actors with different work designations are potentially involved. They cover essential issues experienced by actors in the examined cases pertaining to the appropriation of integrated technologies that will most likely bear similarities to other cases.

5.1 Collective evaluation

Historically, evaluating the organization wide performance of mobile work has been a difficult task. Due to the nature of the work context, great emphasis is generally put on the drivers' ability to swiftly adapt to changing conditions. In doing so, keeping the stationary organization updated is a challenging task, spanning both mobile and stationary parts of the organization. Therefore the UCE was seen as a means for expanding present knowledge of work outcomes and their causes by monitoring driver activities. Ideally, this information would be utilized to set organization wide goals and assess the mobile workforce's compliance with organizational policies such as speed limits, drive time legislation, and other vehicle related metrics. However, controlling the mobile workforce from a central location was still largely viewed as difficult. An illustrative example of features is embedded technology components that constantly remind drivers to use fuel efficient driving styles. As illustrated by a dispatcher from case organization A, initial experiences pertaining to use of such technology were positive:

Before we got this system, you didn't really know about these things. Well, you knew that a certain driver drove too fast, but did it really have that much effect on fuel consumption? Now you get a really good view of the costs of driving too fast, and when you get that, it is easier to tackle the problem.

While embedded vehicle systems generated huge sets of data describing performance down to individual driver and vehicle levels, many dispatchers found that the time invested in assessing newly available metrics mitigated the potential benefits. Although satisfied with the increased level of detail provided, a dispatcher from case organization A commented:

I work more now, since I've got access to more information. With this system I get information on each driver or truck. The time I invest, that's probably the main difference. On the other hand, the analyses are better, more reliable. Earlier, I had nothing to work with, so yes, I work more with this now.

However, there were also concerns that decisions would be taken on false grounds. For example, concentrating on fuel consumption as a variable could prove incorrect as many other factors have to be considered such as the conditions a particular driver operates in and the load factor and cargo weight of the assignments carried out. Such a detailed analysis was not available in any of the systems used by the case organizations. This meant that to get the answers sought the frequent adaptations to changing field conditions meant that the boundary spanning dimension of evaluation processes became even more crucial. As asserted by the manager of case organization D, it was not deemed feasible due to the complexity and time involved:

Well, we have made some remarks, but we have not taken it very far actually. There are lots of things beyond their [the drivers] control that influence their driving. For example, we have a number of trucks involved in high security assignments where you can't stop. They have to follow the convoy and they can't deviate. There are also other things that are more important. If you choose a smaller non-toll road you might save money while the fuel consumption goes up. So it's *not that easy. If you want that kind of analysis, it takes a lot more time and that's something that I don't have.*

While the positive consequences illustrate opportunities to follow the workflow of multiple mobile resources the challenges involved in resource management of mobile resources were evident. The digital trace of mobile work created in systems was at worst found incomplete and/or inconsistent with the context in which the mobile resources operate and at best resource consuming in terms of analysis and use. Though not having the anticipated effect, the use of UCE for understanding mobile work practice still had an impact. Rather than simply rationalizing the process of evaluation by supplying the stationary organization with performance data, the implementation of a UCE led to a heightened awareness of the collective effort required. As depicted in Figure 4, the prevailing prioritization on adaptive task execution coupled with the boundary spanning nature at the heart of sense making of mobile work were influential factors promoting a collective evaluation practice being enacted.

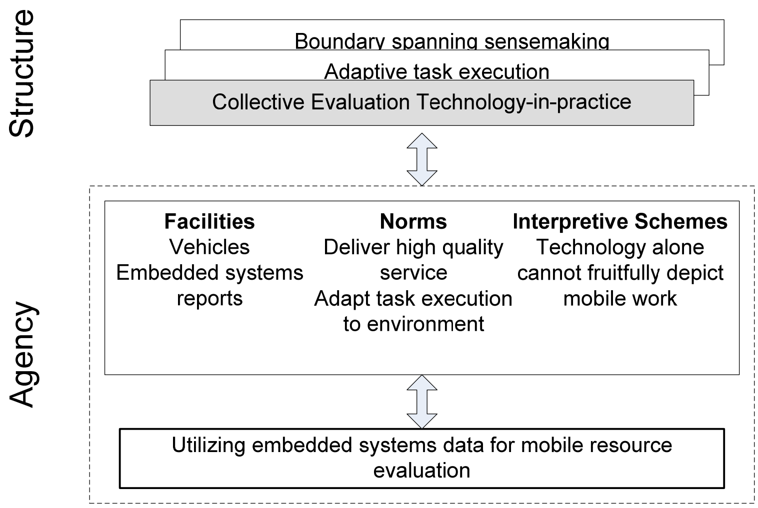

Figure 4: Collective Evaluation technology-in-practice

Furthermore, it was clear that in such cases that the vendor of embedded vehicle technology was also the manufacturer of the truck into which it was installed, there existed additional complexity. A manager from case organization D explained:

I have mentioned to them that they do get advantages themselves. The manufacturer monitors the trucks that we have so they can see when we get error codes or when the truck starts to break down. Then they can be prepared so that the workshop has the necessary parts to replace. So in the end, that's another use of it for the brand workshop.

There were no clear distinctions between the use intended to benefit the vendor/manufacturing organization and the transport organization. These motives and use incentives were essentially experienced as external to the transport organization who felt no immediate use of such features.

5.2 POWER REDISTRIBUTION

Managing day to day operations includes the planning of organization wide tasks to be performed by mobile units. This work involves disseminating work plans to the allocated resources and continuous efforts to communicate progress and changes between dispatchers and drivers as well as transport customers. By implementing a UCE, organizations hoped to rationalize the entire process. Essentially, a formalized communication through mobile and stationary components of the UCE conveyed work process related information updates dynamically. On the stationary side this affected horizontal information sharing. Generally, an individual dispatcher is responsible for managing and reporting on the workflow of a certain group of vehicles. By granting dispatchers access to each others' system views, clearly showing the customer specific information pertaining to an assignment carried out by a mobile unit, the introduction of the UCE increased workflow transparency. A dispatcher from case organization B explained:

If I get a booking and enter it into the system, I don't have to be there personally if that customer calls and wants to know something. All information is there. It becomes an asset for everyone. I think that is good.

The recurring task of responding to customer information needs become less dependent on individual dispatcher availability as dynamically updated information was in a sense transferred to the traffic controller collective.

Prior to the implementation of the UCE, the transfer of process data between separate stationary transport data systems and mobile order systems information transfer was conducted manually. As noted by several respondents, this manual information input was regarded a problem with important implications. Primarily, manual handling of information transfer was time consuming. Also, the risk of information corruption increased with the number of manual replications and/or modifications performed. As recognized by the manager of case organization C, stationary users of integrated systems saw these problems eliminated as the need for manual data transfer was minimized:

If you had an assignment in the transport management system, you had to enter it once more into Dynafleet before you could send it to the driver. Now it's sent immediately. It saves a lot of time.

Traditionally the tasks performed by dispatchers and drivers were entirely separated. However, many drivers asserted that the UCE altered their work designation. As a driver from case organization A commented, they now had to perform work previously dedicated to the stationary workforce:

It all started when we got mobile phones, which was all right. Then we got an order system and had to manage all order documentation ourselves. And now this! [Referring to the in-vehicle order management component] Some feel that we get more and more of the paper work. On the other hand, we don't have to wait for them [the dispatchers] to sort the order receipts out before leaving. Now, when you have loaded you do it yourself on the mobile terminal when you want to.

While this indicates that such a task reallocation was unwelcome and regarded as an additional burden, it also provided them the opportunity to manage their workflow independently.

By making information globally available, a UCE could alter the power balance in the implementing organization. This was especially evident in case organization B where increased information access was viewed as potentially disruptive by the stationary part of the organization. As they previously were the sole holders of searchable and detailed information pertaining to revenue on assignment level, they now feared that drivers would question the authority of the dispatchers, demanding access to the most profitable assignments while shunning those less lucrative. The manager of case organization B was acutely aware of such potential effects:

They get a lot more information now, so hopefully it has become easier for the haulers to follow up so they get paid for their assignments. They might also get an idea of what assignments are better to take than others. All are not equally profitable. This is for good and for worse, because if you discover that some assignments yield little in return, you won't take those assignments.

Since the stationary organization neither had an obligation nor could optimize the revenue of individual member road haulers, this was seen as potentially disruptive to the current way of organizing mobile resources.

In sum, these positive and negative consequences demonstrated a clear organizational impact. The highly centralized rationalistic logic of implementing a UCE for mobile-stationary order management processes was largely successful. However, power-structures were in part contested by the inherent capability of the UCE disseminating more detailed information to both dispatchers and drivers.

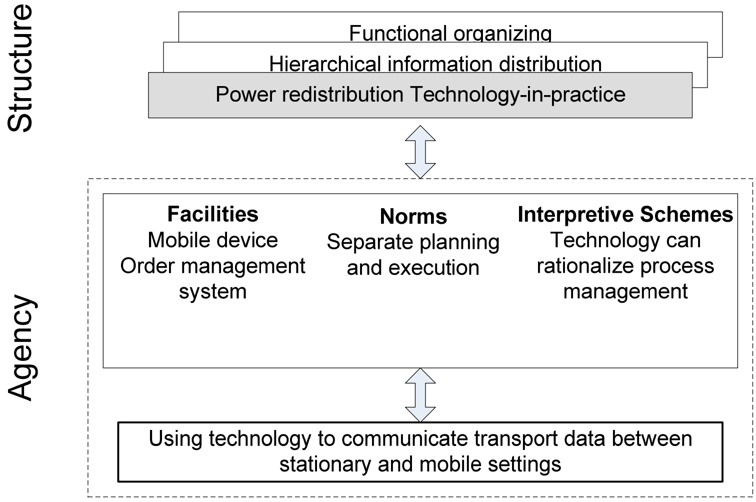

Figure 5: Power redistribution technology-in-practice

The integration of mobile and stationary computing resources entails a previously unavailable transparency as well as a redistribution of tasks and responsibilities among actor groups who see new threats and opportunities arise. However, where fundamental mobile-stationary power structures were threatened, the existing functional separation was called upon to enact a reinforced practice of centralized resource allocation through the UCE.

5.3 Multi-channel communication

In their routine work, case organizations exhibited a temporal diversity in that different rhythms applied to mobile and stationary parts simultaneously. The need for collaborative sense making spanning these boundaries was a major issue as dispatchers became overpowered by an indispensable and frequent direct communication with drivers. The UCE was partly implemented for its envisioned capability to rationalize this communication between stationary and mobile actors. Such system support includes text messaging services for reducing redundant verbal communication between dispatchers and drivers. While messaging services imply two-way communication between drivers and dispatchers, actual usage indicated a different mode of interaction. Dispatchers generally posted textual messages to drivers, thereby gaining the benefit of a one-way communication channel. Drivers were by comparison passive recipients. This was seemingly partly attributed to mobile device manipulation difficulties. According to drivers, many found the mobile device user interfaces ill adapted to this type of interaction, especially in conjunction with driving. Still, as noted by the dispatcher of case organization A, this time independent communication was regarded as beneficial and time saving in dispatcher-driver communication:

If I call someone [a driver] and the phone is busy, I just send a message 'call me' and in a short while I'll get a call. It could be something concerning vehicle maintenance or that the driver needs to contact someone or similar. I find that very good. And what's really good is that even if the driver is not at work, you can send a message in the evening, and then the following morning when he logs on he'll get it.

Furthermore, the introduction of messaging systems linking mobile and office workers offered an unanticipated possibility to track communication history. This brought a greater sense of reassurance in communication as both drivers and dispatchers experienced that conversations were subject to less afterward interpretational disputes and frustration. A driver from case organization A explained:

This gives us drivers a sort of protection. Because if we have sent a message, they [the dispatchers] have got the time it was sent and everything on the computer. It is stored there, so there can't be any unnecessary arguments.

However, there was also a type of delivery apprehension relating to the reliability of the mobile-stationary communication technologies involved. As illustrated by the manager of case organization C, senders were not confident that messages actually reached the recipients in time:

The way drivers and dispatchers interact is different now. Sometimes, when there is a lot of communication going on, the drivers have felt that they were not getting answers fast enough. They then wonder if their messages have been read at all. This can be especially frustrating when waiting for a return load.

Indeed, technical problems related to the underlying information transfer protocols (most notably GSM/SMS) rendered a new and unwelcome uncertainty. Considering the inherent temporal diversity in these organizations, such problems were critical. This caused senders to confirm the reception of textual messages by phone, thereby eliminating the time saving benefits sought, if not making communication even more resource demanding. A dispatcher of case organization D commented:

It sometimes happens that they [the drivers] get important messages much later than they should have. If you take for granted that they arrived in due time, things go wrong and you have to correct them later. So the only way to know is to call them.

While both mobile and stationary actors utilized the UCEs to increase accountability by minimizing communicational ambiguity, sensemaking limitations were evident. Taking for granted ad hoc information that do not fit the format of systems messaging or relying solely on textual messaging was regarded a dangerous approach, as the recipients' interpretation could not be confirmed as is the case with synchronous verbal conversation. The manager of case organization C exemplified:

They would send a message 'Load eight pallets there and five there'. But with this system you can't add 'You must put those pallets in front because…'. The misunderstandings can be very costly, if you don't communicate properly. It [formalized and computerized process messages] must never replace talking.

Summarizing the experienced positive and negative consequences for mobile-stationary communication, a clear effect on the communication patterns between dispatchers and drivers was identified. Most organizations implemented a UCE partly to overcome a mobile stationary communications bottleneck. While several users appreciated the time independence in ad hoc

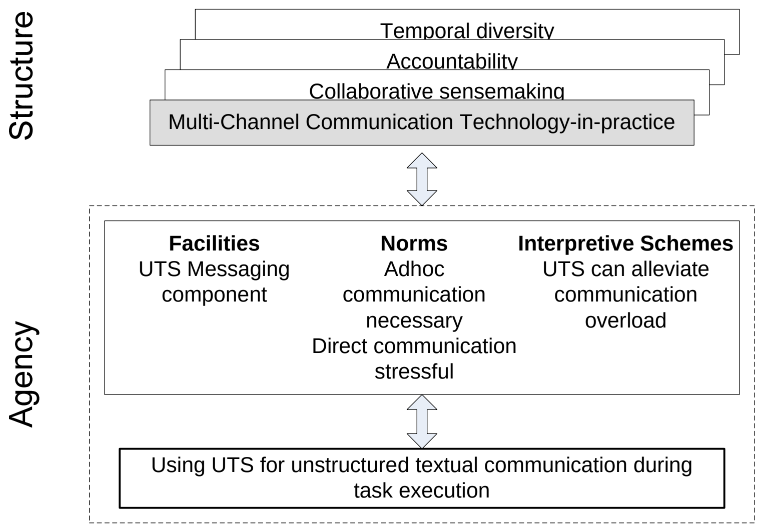

Figure 6: Multi-channel communication Technology-in-practice

communication created by the integrated technology, they also experienced a diminished control of the communication process.

The cooperative effort involved in constructing the meaning of mobile-stationary conversation became subject to limitations imposed by the UCE. Indeed, such sense making efforts were a challenging side effect in attempts to reduce temporal interdependency in communication between stationary and mobile actors. Therefore, rather than simply rationalizing communication, the UCE was frequently enacted as a communication channel amongst others to counter such tendencies, thus hampering the decrease of overload originally anticipated.

6 DISCUSSION

Following the ongoing diffusion of mobile and wireless communication services in everyday life, the expansion of UCEs have emerged as a vital area of research in IS. As indicated in recent research, its implications span over multiple levels of analysis and call for new research approaches (Lyytinen and Yoo 2002b). Indeed, the heterogeneous and distributed nature of these computing environments requires both technology-intense (March et al. 2000) and socially informed research (Jessup and Robey 2002). In fact, most ubiquitous computing research issues can be productively approached with research efforts that tackle the intertwining of social and technical elements playing out in attempts to design, implement, and use such integrated technologies (Lyytinen and Yoo 2002b). In this paper, a practice lens has been applied to a multi-setting study of similar contexts and technologies. Analyzing the results, three instances of technology-in-use were identified: collective evaluation, power redistribution, and multi-channel communication. While not claiming that this is in any way an exhaustive list, they are nonetheless of importance for UCEs where coordination of diverse sets of mobile units is central to organizational performance.

In filtering and combining information from mobile, embedded, and stationary sources lies the potential of increased understanding of the organization (cf. Jessup and Robey 2002). I this case, the UCEs were anticipated to reveal insights into mobile work performance and suggest areas for improvement whilst rationalizing the existing process of doing so. However, the studied organizations were largely unsuccessful in their attempts to utilize the digital trace of mobile work created in UCEs as it was found incomplete and/or inconsistent with the dynamic context to which the mobile actors continuously adapt. Simply put, the technology was found to impose a decoupled and simplified view of efficiency. The emphasis was on parameters endogenous to the embedded components while many exogenous factors were missing. The meaning of this limited digital trace within the UCE had to be negotiated between mobile and stationary actors. The existing focus on boundary spanning collaborative sense making was thus further reinforced as a collective evaluation technology-in-practice was enacted.

There were clear indications that the UCEs had the potential to blur the boundaries between extant mobile and stationary work designations and related power distribution. Here the enactment of the environments drew on a combination of extant structures. Attempts to realize seamlessly integrated computing support caused new workflow configurations that partially changed organizational structure. The information transparency created by such integrated solutions rendered changes in the relation between the mobile and stationary workforces. As an example, mobile workers found themselves in a position where they performed tasks previously attributed to the stationary personnel. The extant structures of clear cut functional organizing and strictly hierarchical information distribution was initially called upon by the mobile workers to limit such tendencies.

The stationary actors enacted UCEs in a similar way but utilized extant structures in a very different way. In a situation where independent drivers were confronted with detailed information on the financial viability of individual assignments, stationary personnel saw their authority to coordinate and control the way in which transport assignments were allocated undermined. However, the increased autonomy conferred by these UCEs paved the way to a moderated acceptance and an enactment of a power redistribution technology-in-practice. This example bears similarities to what has been seen in traditional integrated IS environments conferring both empowerment and control potential (Sia et al. 2002). However, it does highlight the importance of the more complex organizational contexts, meaning that the technology was enacted in slightly dissimilar ways in organizations where an extant structure of decentralized authority was already present. It also suggests that organizations have to adapt their organizing logic to the structural changes imposed by interconnected organizational and technical elements of heterogeneous and distributed computing environments (Lyytinen and Yoo 2002b; Sambamurthy and Zmud 2000).

Transport firms' desire to rationalize mobile-stationary communication by employing new technology occasioned both intended and unintended effects on communication patterns. The independence of time in ad hoc communication was widely recognized as beneficial. While establishing this independence, however, the cooperative effort involved in constructing the meaning of conversation became subject to limitations imposed by the communication systems. All users viewed the diminished opportunities for individual interpretation as helpful, but simultaneously noticed new issues of uncertainty related to their common understanding of mobile work. Indeed, such sensemaking difficulties had direct consequences for mobile work practice as well as social interaction. However, there were frequent workarounds utilizing previous techniques incorporating mobile phones due to message delivery apprehension and rigid representations of processes and settings. In essence, the communication technology originally intended to limit communication became just yet another communication channel joining the present technologies and associated use patterns.

Table 6 summarizes enactments found together with technical and institutional conditions in play and the resulting technological and structural consequences. In keeping with findings from cases of traditional integrated information systems (Boudreau and Robey 2005), no discernable technological consequence could be found in any of the cases. Of the enactments encountered, only one could be associated with evidence of significant change of preexisting structures.

Technology–in-practice	*Case*	*Technological conditions*	*Institutional conditions*	*Processual consequences*	*Technological consequences*	*Structural consequences*
Collective Evaluation	A	CAN-bus	Hierarchical	Increased collaboration & negotiation in evaluation	None	Reinforce
	C	CAN-bus Fleet positioning	Hierarchical	Limited (discontinued)	None	Reinforce
	D	CAN-bus Fleet positioning	Hierarchical	Limited (discontinued)	None	Reinforce
Power redistribution	B	Fleet positioning Mobile order management Stationary order management	Competitive	Blurred functional boundaries	None	Power balance shift Role shift
	A	Mobile order management	Hierarchical	Blurred functional boundaries	None	Power balance shift Role shift
Multi-channel communication	A	Text messaging Mobile phone	Hierarchical Accountability	Reduced time-space divide	None	Reinforce
	C	Text messaging Mobile phone	Hierarchical Accountability	Reduced time-space divide	None	Reinforce
	D	Text messaging Mobile phone	Hierarchical Accountability	Reduced time-space divide	None	Reinforce

Table 6: Actions, conditions, and consequences

The initial research question was: *How does the constant availability of information in multiple social and physical contexts impact users and organizations in an emerging integrated information environment?* Based on this discussion, it is clear that changes in the relation between mobile and stationary work practices did occur. However, they were not necessarily anticipated by the management of implementing organizations. Many of the rationalistic objectives were at best marginally fulfilled as users sought and found ways to circumvent and adapt their use of the integrated technologies. This clearly indicates that the technological and social mobile-stationary coupling introduced by UCEs was moderated by existing social structures and the actions of knowledgeable individuals. In essence, many of these pre-existing patterns of action remained or were reinforced. The most radical change was attributed to the enactment of the UCE with regards to power redistribution. This type of enactment was most pronounced in case B where the already competitive environment was further heightened. To a lesser extent, similar effects were evident in case A. However, the competitive element was of less influence. Instead, the blurring of traditional functions within the organization resulted in a moderate shift of power from the previously dominant stationary to the mobile actors.

7 Implications for Research and Practice

The implementation of integrated technologies is becoming more complex. A multitude of new information technology is increasingly intertwined with the everyday practice of organizations (Lyytinen and Yoo 2002a; 2002b). This paper has explored one such setting. However, there is reason to believe that these results can be utilized in similar settings where a host of mobile, embedded, and stationary information technologies are enacted across contextual boundaries. The term "integrated" has served to portray an environment of heterogeneous yet coupled technologies and practices. The type of UCE analyzed in this research is arguably a somewhat limited example of such phenomena. The implementations were found partial as various potential technological linkages were not implemented.

Furthermore, the UCEs components were technologically rather tightly coupled. However, they were all composed of heterogeneous technologies supplied by collections of vendors. Thus, in comparison to the integrated stationary technology reported by Boudreau and Robey (2005) they were not entirely monolithic. Nonetheless, the findings will most likely hold in UCEs characterized by more loosely coupled technologies, if not even becoming more pronounced.

In terms of practical implications, this research suggests that UCEs seem best used as a means to increase collaboration spanning the boundaries of mobile and stationary contexts. Regardless of original intentions, implementing organizations should therefore expect associated boundary spanning collaborative processes becoming intensified and more detailed rather than reduced and rationalized. This should be carefully considered before constructing an organizational UCE as such outcomes might very well conflict with the underlying managerial rationale.

In terms of theoretical implications there was no evidence that technological malleability conferred by user configurable applications and the rigidity conferred by interconnectivity and interdependence acted as opposing forces on agency. Indeed, none of the UCEs studied showed signs of extensive user malleability. However, evidence suggests that the coupling of dispersed contexts conferred by UCEs did not prevent individual agency in interacting with technology. The users were nonetheless able to reinvent their use of the technologies to some extent. In many of these instances, the net result was an intensified collaboration spanning the mobile-stationary boundary regardless of the original intentions of management.

Furthermore, parts of enactments reported here seemed influenced by structures of external origin. As noted by Walsham (1993), Giddens argues that action in a focal setting is conditioned by and in turn conditions social structure which extends beyond the focal setting. In the studied settings, issues related to previous design activities were often seen as an important influence on technology enactment. As indicated by prior IS research, information technology tends to reflect the context in which they were designed (Orlikowski and Robey 1991; Winograd and Flores 1986). This was confirmed by respondents in this study. Actors outside the organizational boundaries of the focal setting imposed a notable influence. In particular the focus on endogenous vehicle parameters was thought to derive from the heterogeneous vendors' process of designing the various components of the UCEs. In particular, there were speculations on why vendors of embedded technology were seemingly unable to fruitfully add to and collaborate with those designing other mobile and stationary components. This could have affected the perceived ways of enacting such technology negatively.

Orlikowski et al. (1995) categorize human actors into those that are users and those that structure the technology for the users in the process of technology-use mediation by organizationally sanctioned *meta-structuring*. However, they refer to ongoing human intervention in technology use such as on-site training and not to time-space distant design decisions. The absence of mediation is nonetheless an indication of the way in which enactments of environments of heterogeneous technologies evolve as there is no single actor capable of expressing its full potential. Rather, there is a group of heterogeneous actors with knowledge limited to their specific sphere of interest. Indeed, in this sense, it would seem that technologies are coupled faster than the supplying organizations**.** In keeping with Lyytinen and Yoo (2002b) and given this essential characteristic of UCEs, the central idea within established data-intensive methodologies of studying local behaviors outside the reach of networked components of stationary, embedded, and mobile technologies seems foregone. Instead methodologies should enable studying interrelationships and patterns among various individuals and technological tools dispersed across time and space. Clarifying such boundary spanning influences on technology enactments would therefore seem to require an expanded empirical setting including vendor organizations that would enable deeper knowledge on the relation between agency, structure and technology. By studying such environments, the increasingly complex endeavor process of designing and implementing organization wide technologies spanning multiple technological bases can be better understood.

8 REFERENCES

Akinci, B., Hendrickson, C., and Karaesmen, I., "Exploiting Motor Vehicle Information and Communications Technology for Transportation Engineering," *Journal of Transportation Engineering*, (129:5), 2003, pp 469-474.

Andersson, M., and Lindgren, R., "The Mobile-Stationary Divide in Ubiquitous Computing Environments: Lessons from the Transport Industry," *Information Systems Management*, (22:4), 2005, pp 65-79.

Angeles, R., "RFID Technologies: Supply Chain Applications and Implementation Issues," *Information Systems Management*, (22:1), 2005, pp 51-65.

Barley, S. R., "Technology as an Occasion for Structuring: Evidence from Observation of CT Scanners and the Social Order of Radiology Departments," *Administrative Science Quarterly*, (31:1), 1986, pp 78-108.

Boudreau, M.-C., and Robey, D., "Enacting Integrated Information Technology: A Human Perspective," *Organization Science*, (16:1), 2005, pp 3-18.

Cousins, K. C., and Robey, D., "Human agency in a wireless world: Patterns of technology use in nomadic computing environments," *Information and Organization*, (15), 2005, pp 151-180.

DeSanctis, G., and Scott Poole, M., "Capturing the Complexity in Advanced Technology Use: Adaptive Structuration Theory," *Organization Science*, (5:2), 1994, pp 121-147.

Giannopoulos, G. A., "The Application of Information and Communication Technologies in Transport," *European Journal of Operational Research*, (152:2), 2004, pp 302-320.

Giddens, A., *The Constitution of Society - Outline of the Theory of Structuration*, Polity Press, Cambridge, 1984.

Henfridsson, O., and Lindgren, R., "Multi-contextuality in ubiquitous computing: Investigating the car case through action research," *Information and Organization*, (15:2), 2005, pp 95-124.

Jessup, L. M., and Robey, D., "The Relevance of Social Issues in Ubiquitous Computing Environments," *Communications of the ACM*, (45:12), 2002, pp 88-91.

Jonsson, K., and Holmström, J., "Ubiquitous computing and the double immutability of remote diagnostics technology: An exploration into six cases of remote diagnostics technology use," IFIP WG 8.2 International Working Conference, Springer, Cleveland, Ohio, 2005.

Jonsson, K., Westergren, U. H., and Holmström, J., "Technologies for value creation: An exploration of embedded systems use in a business model context," Information Systems Research in Scandinavia (IRIS) 27, plenary paper, Falkenberg, Sweden, 2004.

Lyytinen, K., and Yoo, Y., "Issues and Challenges in Ubiquitous Computing," *Communications of the ACM*, (45:12), 2002a, pp 63-65.

Lyytinen, K., and Yoo, Y., "Research Commentary: The Next Wave of Nomadic Computing," *Information Systems Research*, (13:4), 2002b, pp 377-388.

Lyytinen, K., and Yoo, Y., "Social impacts of ubiquitous computing: Exploring critical interactions between mobility, context and technology," *Information and Organization*, (15), 2005, pp 91-94.

March, S., Hevner, A., and Ram, S., "Research Commentary: An Agenda for Information Technology Research in Heterogeneous and Distributed Environments.," *Information Systems Research*, (11:4), 2000, pp 327-341.

Müller, C. D., and Zimmermann, H.-D., "Beyond Mobile: Research Topics for upcoming Technologies

in the Insurance Industry," Proceedings of the 36th Hawaii International Conference on System Sciences, IEEE Computer Society Press, Hawaii, 2003.

Orlikowski, W., "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations," *Organization Science*, (11:4), 2000, pp 404-428.

Orlikowski, W. J., "The duality of technology: Rethinking the concept of technology in organizations," *Organization Science*, (3:3), 1992, pp 398-427.

Orlikowski, W. J., "Improvising Organizational Transformation Over Time: A Situated Change Perspective," *Information Systems Research*, (7:1), 1996, pp 63-92.

Orlikowski, W. J., and Robey, D., "Information Technology and the Structuring of Organizations," *Information Systems Research*, (2:2), 1991, pp 1-28.

Orlikowski, W. J., Yates, J., Okamura, K., and Fujimoto, M., "Shaping Electronic Communication: The Metastructuring of Technology in the Context of Use," *Organization Science*, (6:4), 1995, pp 423-444.

Pozzebon, M., "Demystifying the Rhetorical Closure of ERP Packages," Twenty-Second International Conference on Information Systems, New Orleans, 2001, p. 329–337.

Robey, D., and Boudreau, M.-C., "Accounting for the Contradictory Organizational Consequences of Information Technology: Theoretical Directions and Methodological Implications," *Information Systems Research*, (10:2), 1999, pp 167-185.

Roy, J., "Recent trends in logistics and the need for real-time decision tools in the trucking industry," the 34th Hawaii International Conference on System Sciences, U.S.A., 2001.

Ryberg, T., "Fleet Management and Wireless M2M

Second Edition, Europe 2006," Berg Insight.

Sambamurthy, V., and Zmud, R., "Research Commentary: The Organizing Logic for an Enterprise's IT Activities in the Digital Era - A Prognosis of Practice and a Call for Research," *Information Systems Research*, (11:2), 2000, pp 105-114.

Schultze, U., and Orlikowski, W. J., "A Practice Perspective on Technology-Mediated Network Relations: The Use of Internet-Based Self-Serve Technologies," *Information Systems Research*, (15:1), 2004, pp 87-106.

Sia, S. K., Tang, M., Soh, C., and Boh, W. F., "Enterprise Resource Planning (ERP) Systems as a Technology of Power: Empowerment or Panoptic Control?" *The DATABASE for Advances in Information Systems*, (33:1), 2002, pp 23-37.

Strauss, A., and Corbin, J., *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*, SAGE, Newbury Park, 1990.

Sørensen, C., and Pica, D., "Tales from the police: Rhythms interaction with mobile technologies," *Information and Organization*, (15:2), 2005, p 125–149.

Walsham, G., *Interpreting Information Systems in Organizations*, John Wiley & Sons, Chichester, 1993.

Winograd, T. A., and Flores, F., *Understanding computers and cognition: A new foundation for design*, Addison-Wesley, Reading, Mass., 1986.

THIRD PAPER

3 MULTI-CONTEXTUALITY IN BOUNDARY-SPANNING PRACTICES

RIKARD LINDGREN, MAGNUS ANDERSSON, OLA HENFRIDSSON

ABSTRACT

The capability to establish boundary-spanning practices within and across organizations has for long been recognized as a key strategic resource. As organizations are becoming distributed and dynamic, they will be increasingly populated by multiple functional, geographical, hierarchical, and professional boundaries. The inherent complexity of such settings makes it difficult for organizations to leverage their boundary-spanning practices. IT systems have been hailed as a critical enabler of boundary-spanning. However, there is little knowledge on how organizations are affected by the introduction of different types of IT systems. Building on an interpretive case study of Swedish transport organizations, this paper explores consequences of sensor technology for boundary-spanning. The paper contributes with an understanding of what co-existing use contexts mean for boundary-spanning practices. A theoretical implication is that such multi-contextuality requires an integrative view on boundary-spanning that combines insights from the organizational innovation and work practice literatures.

Key words: Boundary-spanning, innovation, multi-contextuality, sensor technology, ubiquitous computing environments, work practice

1 INTRODUCTION

As an effect of increased specialization and distribution of work, organizations will be increasingly fragmented by multiple functional, geographical, hierarchical, and professional boundaries. It is therefore necessary to develop capabilities for combining multiple sources of expertise (Kogut and Zander 1992) and establishing boundary-spanning practices (Levina and Vaast 2005a).

Given the importance of boundaries, there is a significant body of research that examines boundary-spanning activities in organizational innovation (see *e.g.*, Cohen and Levinthal 1990; Friedman and Podolny 1992; Leifer and Delbecq 1976; Tushman and Scanlan 1981) and everyday work practices (see *e.g.*, Balogun *et al.* 2005; Carlile 2002; Pawlowski and Robey 2004) Early on, the innovation literature identified the significance of environmental information gathering and assimilation to organizational renewal. Such information gathering and assimilation is associated with specific boundary-spanning roles at different stages in the innovation process (Tushman 1977). Later on, practice perspectives have focused on boundary-spanning as a sensemaking activity that situates new information in embedded and local work practices. Such sensemaking is dependent on human agents' capacity to establish new recurrent cross-boundary practices based on shared institutional meanings (Carlile 2002; Pawlowski and Robey 2004).

In view of the increasing ubiquity of IT in organizational life, it is not surprising that its role in boundary-spanning has attracted recent attention in the literature. In particular, IT-artifacts have been recognized as having the potential to be adapted to local needs, while at the same time providing a source of common identity across boundaries (*cf.* Star 1989). In the work practice literature, the notion of boundary object has been used to capture this potential and to advance the idea of IT as an important resource for boundary spanners in establishing practices that bridge communities-of-practice (Levina and Vaast 2005a; Pawlowski and Robey 2004).

Despite the recent interest in IT's role in boundary-spanning practices, it is fair to say that the extant literature pays little attention to differences between types of information systems. The danger in doing this is the inattention to potential consequences of specific qualities of the technology when studying boundary-spanning practices. In this paper, we explore ubiquitous computing environments as a specific type of information system and trace its implications for boundary-spanning practices. This is motivated by the multiple dimensions of boundary-spanning that ubiquitous computing environments encompass when adopted and used in organizational settings (Fano and Gershman 2002; Lyytinen and Yoo 2002). In particular, we concentrate on the multi-contextuality, *i.e.*, the co-existence of multiple use contexts, of ubiquitous computing environments (Henfridsson and Lindgren 2005) and the particular challenges associated with sensor technology use in boundary-spanning practices. We propose that the co-existence of multiple use contexts requires an integrative view on boundary-spanning in which insights from the organizational innovation and work practice literatures are combined. In this vein, this paper addresses the following research question: what does sensor technology mean for boundary-spanning practices in distributed settings? Building on an interpretive case study (Klein and Myers 1999; Walsham 1995) of Swedish transport organizations, the contribution of this paper is an analysis of the complex relationship between boundaries of co-existing use contexts and technology support in organizational boundary-spanning.

The paper proceeds as follows. First, we review related research on boundary-spanning and the use of IT in boundary-spanning practices. This is followed by an examination of the notion of multi-contextuality and its relation to boundary-spanning. Thereafter, we describe the research context and details about the method applied. Then, we present the result from our study and analyze the role of sensor technology in boundary-spanning processes. In our concluding sections, we discuss implications for research and practice.

2 PERSPECTIVES ON BOUNDARY-SPANNING

Over the years, the notion of boundaries has been a central phenomenon in attempts to theorize organizations. Using various theoretical lenses, researchers have explored the nature of boundaries as the demarcation between an organization and its environment (Scott 1992). In the literature, distinct conceptions like efficiency, power, competence, and identity have been proposed to offer unique perspectives on organizational boundaries (Santos and Eisenhardt 2005).

However, as modern organizations are becoming increasingly fragmented by multiple functional, geographical, hierarchical, and professional boundaries, recent literature has developed broader views of boundaries as to provide a deeper understanding of organizations (see *e.g.*, Santos and Eisenhardt 2005). While multiplicity of boundaries can be traced to increased specialization of work, it creates the need for organizations to develop capabilities enabling integration of multiple sources of expertise. Indeed, the capability to leverage boundary-spanning practices within and across organizations has for long been recognized as a central competitive dimension of firms in the knowledge economy (Kogut and Zander 1992).

On a general level, boundary-spanning can be seen as the activity of making sense of peripheral information that is perceived relevant to expand the knowledge at the center of a given organizational context. In reviewing extant research contributions, boundary-spanning has attracted a great deal of attention in a variety of literatures including decision science (Choudhury and Sampler 1997), human relations (Russ *et al.* 1998), logistics (Morash *et al.* 1997), organizational innovation (Cohen and Levinthal 1990), psychology (Voydanoff 2005), and work practice studies (Kellogg *et al.* 2006). Focusing on different aspects of this multi-facetted topic, innovation and work practice theories are dominant theoretical perspectives underlying such research and of particular interest to this investigation (see Table 1).

Theoretical perspective	***Key references***	***View on boundary-spanning***
Innovation	• Cohen and Levinthal (1990) • Friedman and Podolny (1992) • Leifer and Delbecq (1976) • Malhotra et al. (2005) • Rosenkopf and Nerkar (2001) • Tushman (1977) • Tushman and Scanlan (1981)	• An information gathering activity aimed at linking new, typically environmental, information to prior knowledge for stimulating innovation. The possession of information is central to competitive advantage.
Work practice	• Balogun et al. (2005) • Carlile (2002) • Hayes (2001) • Kellogg et al. (2006) • Levina and Vaast (2005a) • Levina and Vaast (2005b) • Orlikowski (2002) • Pawlowski and Robey (2004)	• A sensemaking activity aimed at situating general information in the context of local work practices. Situated representation of information is central to learning.

Table 1. Theoretical perspectives on boundary-spanning

The innovation literature recognizes boundary-spanning as something essential to organization renewal. The innovation perspective views boundary-spanning as an information gathering activity aimed at linking new, typically environmental, information to prior knowledge for stimulating innovation. Underlying this view is an assumption that acquiring and assimilating new information are central to competitive advantage. Cohen and Levinthal's (1990) seminal work on absorptive capacity epitomizes this tradition. They define absorptive capacity as the “ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends” (p. 128). In this vein, an organization’s absorptive capacity depends both on the organization’s direct interface with the external environment and on the transfer of knowledge across and within organizational boundaries. Many innovation studies focus on the boundary and communication channels between the organization and its environment (Cohen and Levinthal 1990; Leifer and Delbecq 1976; Rosenkopf and Nerkar 2001). Such cross-boundary communication can often involve several special boundary roles over different phases in the innovation process (Friedman and Podolny 1992; Tushman 1977; Tushman and Scanlan 1981). This activity is performed by so-called boundary spanners, *i.e.*, individuals who operate at the periphery or boundary of an organization, relating the organization with elements outside it (see *e.g.*, Cohen and Levinthal 1990; Tushman 1977). Essentially, these individuals scan the environment for new information, attempting to determine its relevance vis-à-vis information already assimilated in the organization. In this boundary-spanning process, the individual, the organization, and the environment are parts of a network of interactions and organizational knowledge creation (Cohen and Levinthal 1990).

The work practice literature recognizes boundary-spanning as something essential to learning. Boundary-spanning is typically seen as a sensemaking activity aimed at situating information in the context of local work practices. In this regard, this stream of research primarily focuses on boundary-spanning across internal boundaries of the organization (Balogun *et al.* 2005). Indeed, a distinguishing feature of the practice lens perspectives is their emphasis on situated or embedded work practices (Carlile 2002; Kellogg *et al.* 2006; Schultze and Orlikowski 2004). This means that acquisition, interpretation, and meaningful use of context information is best described as interactive processes involving individuals or groups who routinely transform such information into action through their enacted and situated knowledge (*cf.* Orlikowski 2002). Such processes are not necessarily accomplished by nominated boundary spanners, but typically emerge when individuals, boundary spanners-in-practice, accommodate the interests of their counterparts (Levina and Vaast 2005a). These boundary spanners-in-practice can be described as knowledge brokers who facilitate information flows across boundaries within organizations (Pawlowski and Robey 2004).

In sum, reflective of different origins and research traditions, the innovation and work practice perspectives represent two broad streams of boundary-spanning research. The innovation literature views boundary-spanning as an information gathering activity that links environmental information to prior knowledge in order to stimulate innovation. In this regard, the development, assimilation, and exploitation of information are central elements to gain competitive advantage. In what follows, we refer to this ambition as the competitive information problem. The work practice literature is focused on cross-boundary sensemaking. In particular, this literature approaches boundary-spanning as an activity aimed at situating information in the context of local work practices. We refer to this ambition as the situated adaptation problem throughout this paper.

3 Boundary-Spanning And The Problem Of Multi-Contextuality

Wide accessibility and geographical reach of IT systems make them a key enabler of boundary-spanning. Research studies that explore the role of IT in boundary-spanning have tended to focus on competitive information (see *e.g.*, Malhotra *et al.* 2005) *or* situated adaptation (see *e.g.*, Hayes 2001; Levina and Vaast 2005a, 2005b). As an example of the former, Malhotra *et al.*'s (2005) absorptive capacity perspective on the RosettaNet B2B initiative in the context of supply chain management illustrates how new partner-enabled market knowledge creation and sharing can be supported by internet technology. The authors' analysis is focused on how inter-organizational systems can support different forms of boundary-spanning partnerships between manufacturers, distributors, and retailers for business innovation. With regard to the situated adaptation problem, however, they convey a relatively ignorant stance. In fact, in the context of standard electronic business interfaces, Malhotra *et al.* (2005, p. 155-156) write that "such standards reduce the need to reprocess information received from diverse partners. Prescribed formats make it easy to interpret and manipulate data, which enhances the acquisition and assimilation capabilities of the receiving enterprise".

Looking at the work practice literature, situated adaptation is at the center of attention. For instance, Levina and Vaast (2005a) explore how boundary-spanning practices emerge locally as an outcome of human agents' accommodation to the interests of their counterparts. In the two case studies, the so-called boundary objects-in-use were intranet applications for information sharing. Using Bourdieu's notion of field, Levina and Vaast's (2005a) exploration is geared towards the construction of joint fields as necessary conditions for successful boundary-spanning.

Despite significant differences between the two perspectives, they both virtually overlook potential differences between technologies supporting boundary-spanning activities. The competitive information studies basically view IT as a tool that provides particular information processing capabilities that are subject to managerial control. The work practice studies tend to focus on how IT, or boundary objects, become resources in local meaning-creation. The risk taken here is that insufficient attention is paid to differences between types of IT-artifacts and the potential of new boundary-spanning opportunities and problems emerging with new technologies.

A candidate technology with potential for opening up a new perspective on boundary-spanning is industry-wide ubiquitous computing environments. Being capable of leveraging digital representations of context information across time and place through sensor technology, such environments have been envisioned to become the eyes and ears of organizational actors in the realm of distributed organizing (Fano and Gershman 2002). There is growing evidence that organizations seek to erect ubiquitous computing environments comprising heterogeneous elements such as office, mobile, sensor technologies as to leverage business propositions and increase customer value (Lyytinen and Yoo 2002).

One example is Jonsson et al.'s (forthcoming) study of a shipboard crane supplier's attempt to design and install a remote diagnostic environment as a means of creating innovative business missions through sensor technology. By integrating sensor technology into the physical goods (*i.e.*, shipboard cranes) that catered for transfer of sensor information to office applications, the supplier was able to develop new customer offers that enable the delivery of lifting services rather than shipboard cranes. An additional example of how sensor technology can render value creation in business settings is reported in Andersson and Lindgren (2005). Using the term ubiquitous transport systems, they discuss seamlessly integrated computing environments applicable to the transport industry. By integrating sensor technology embedded in trucks with mobile and stationary transport systems, the transport organizations viewed the potential of improving mobile resource evaluation and dispatcher-driver communication.

Partly unlike approaches taken in the extant literature, these two studies illustrate that emerging boundary-spanning information systems such as ubiquitous computing environments require that the problems of competitive information and situated adaptation are handled simultaneously. First, sensor technology promises to enable efforts to record and archive digital traces of socio-technical activities and interactions in distributed environments for real time or subsequent review by those not present (Grudin 2002). As Jonsson *et al*. (forthcoming) note, ubiquitous computing environments thus cater for networked business settings that exceed organizational boundaries in time and space. In this way, ubiquitous computing allows for collection and transfer of context data that is useful to a multitude of actors including user organizations and suppliers of technology. However, this usefulness cannot be exploited unless the context data is situationally adapted in local use contexts of each of these actors. Second, once stored in a repository and shared via networks, digital traces can enhance organizations' understanding of the different contexts in which they act (Jessup and Robey 2002). While the identification and sharing of context data may prove difficult enough, delivering such data that can be meaningfully interpreted by a multitude of actors is a grand challenge in itself. As Andersson and Lindgren (2005) observe, simply adding more sensors would never entirely eliminate the challenge of interpreting and understanding the complexity of different contexts. This insight must be understood in light of multiple actors' competitive information strategies.

The presence of competitive information and situated adaptation in these studies can be traced to the multi-contextuality of ubiquitous computing environments, *i.e.*, the co-existence of different use contexts (Henfridsson and Lindgren 2005). Given that the extant literature pays little attention to this multiplicity of boundary practices centered around a single technology, it is worthwhile to further explore consequences of multi-contextuality for the use of sensor technology in boundary-spanning practices. The purpose of our fieldwork and data analysis was to understand the complex relationship between boundaries of co-existing use contexts and technology support in organizational boundary-spanning. This can help us to address the question as to how organizations can better utilize sensor technology in ubiquitous computing environments to make distant events to take place "here and now".

4 METHODOLOGY

4.1 RESEARCH SETTING

A well-functioning transport system is a central component in supporting the mobility of people, competence, goods, and capital across nations, regions, and growth centers. Following the ongoing integration of economies around the world, new emergent transnational institutions and networks challenge the business of local and regional actors. For instance, the Swedish transport industry undergoes changes occasioned by the European Union's "open market", where foreign transport firms have increased their market share considerably. This increase is not only a result of lower cost levels in nearby countries but also due to other firms' closeness to more densely populated areas. In this context, major logistics companies like DHL and Schenker have strengthened their positions on the market.

It is therefore not surprising that Swedish transport organizations are faced with increasing pressures to leverage their business propositions and operations at different points in the supply chain. Whether these pressures concern increased customer service or cost reduction, their operations typically involve an increased utilization of different technologies for coordination of distributed mobile units on a daily basis. Such IT support includes services that offer overviews of their mobile resources by positioning individual trucks, route calculation services to minimize time and fuel expenditures of assignments, and vehicle performance recording services. These services reflect a prevailing distinction between the stationary and mobile contexts in a transport setting (Andersson and Lindgren 2005), where frequent and timely transfer and exchange of information between the two contexts is important to get the job done. In addition, information is also exchanged between the mobile context and the sensor technology provider. The technology provider typically has an interest in using the sensor data in managing customer relationships and new product development. This is an example of multi-contextuality in transport settings.

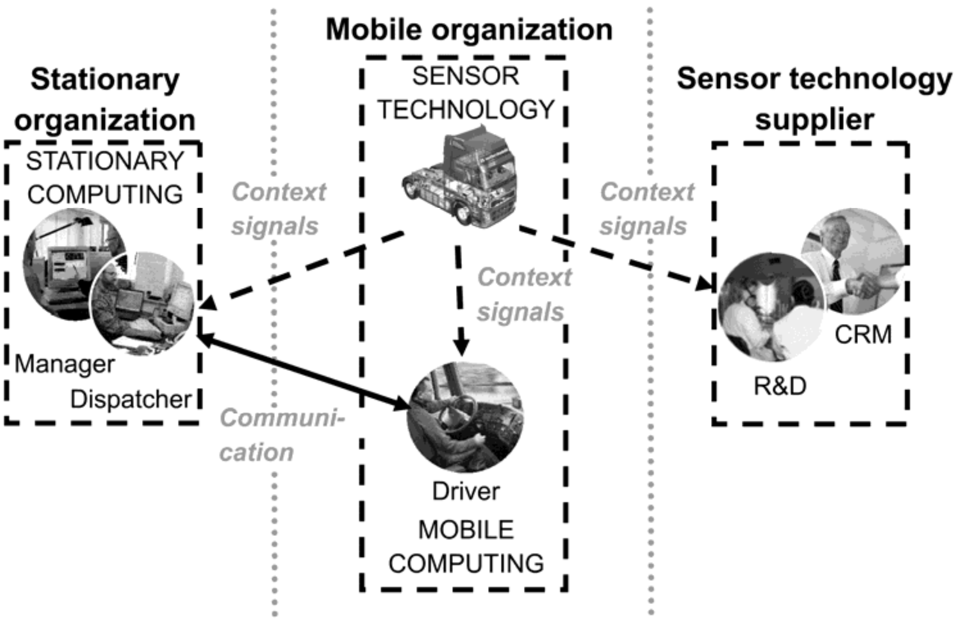

Figure 7. Overview of research setting

Figure 1 provides a simplified overview of the technology-mediated information flows between different contexts in a transport setting. While there exist a number of different roles in transport organizations, users can be divided into three broad categories: managers, dispatchers, and drivers. Managers are responsible for issues such as assembling supply chains, system portfolio management, and overall strategic planning and management, meaning that their use of sensor-fed context data typically can be found at an aggregated level geared towards account analysis and benchmarking. Responsible for the tactical operations management, dispatchers utilize sensor fed stationary computational representations to tap into the ongoing flow of activities in the mobile field operations. Thus, dispatchers are a key user group of such technology in the ongoing information flow across the mobile and stationary contexts found in transport organizations. Drivers, on their part, transport goods, which involves loading, unloading, driving and planning the routes, as well as interacting with clients. Apart from the actual driving, drivers spend much of their time interacting with dispatchers and other drivers in order to handle their daily work. In this interaction, mobile technology support for messaging and order management is routinely used.

4.2 Research design

The data for this study come from an empirical investigation undertaken within an ongoing action research project called “Value-Creating IT for Road Haulage Firms”, involving a set of road haulage companies and system vendors. The data originates from a distinct phase of the project intended to facilitate an in-depth understanding of the role of information technology in daily transport operations. Given the explorative character of this project phase, the study can be described as interpretive in nature, seeking to explore the research phenomena in question through investigating the different meanings people assign to them (Orlikowski and Baroudi 1991). This emphasis builds on the assumption that people act-in-the-world on the basis of their subjective and inter-subjective creation of meaning.

The interpretive case study builds on data from four road haulage companies. There are two properties of the selected sites that made them particularly useful for studying the role of sensor technology in boundary-spanning practices. First, all companies utilized sensor technology to convey digital traces of mobile operations. In this regard, these organizations relied on an assemblage of sensor, mobile, and stationary applications, which taken together can be seen as an emerging ubiquitous computing environment at the business level (see Table 2). Second, all companies had implemented technologies provided by system vendors that were part in the overall research project. This fact gave us access to system vendor views on the role and promises of these technologies for transport business. Multiple voices, not only among different actor groups within the user organization, are an important criterion in interpretive field studies (Klein and Myers 1999).

Case	*Fleet Size*	*Transports*	*Computing environment*		
			Sensor technology	***Mobile applications***	***Stationary applications***
A	300	Goods	**Barkfors Fleet** •Positioning	**Barkfors Fleet** •Mobile order management.	**TDXlog** •Order management
B	325	Bulk, foods, oil, goods	**CoDriver** •Fuel consumption •Distance traveled •Speed	**CoDriver** •Messaging **SAdata** •Mobile order management	**SAdata** •Order management
C	100	Foods, goods	**Dynafleet** •Positioning •Fuel consumption •Distance traveled •Speed	**Dynafleet** •Mobile order management. •Messaging	**Transport 2000** •Order management
D	40	Foods, goods	**FAS** •Positioning •Fuel consumption •Distance traveled •Speed		**In-house system** •Order management •RouteLogics

Table 2. Overview of case organizations

4.3 DATA SOURCES AND ANALYSIS

The study included field research, where interviews, written documentation, technology and system demonstrations, as well as project meetings were the most important sources of data. The interview study included 20 semi-structured interviews with users in the case organizations (managers, dispatchers, and drivers) and system vendor representatives (see Table 3). All interviews were recorded and later transcribed. Lasting between 1 and 3 hours, the interviews covered experiences of technology use, technology strategy, work practice, and communication practices. The interviews with system vendor representatives (area or product managers) concerned current design strategies employed, relations to other technologies, and envisioned usages of the technology. Key questions on these topics were followed by questions that depended on respondent answers.

Category	*Number of interviews*
Drivers	4
Dispatchers	6
Managers	4
Vendor representatives	6

Table 3. Respondents

As recognized in the literature on interpretive research, the interpretations of the researcher are based on interpretations of the respondent (Van Maanen 1979). Since interpretations are implied in any verbal communication, our interpretations of sensor technologies are likely to have influenced the respondents' interpretations during the course of the study. Referred to as double hermeneutics (Giddens 1976), we tried to hamper such tendencies by conducting the interviews in an open-minded manner as to avoid any over-directing, which potentially would trigger testimonies that depict presuppositions of the researcher rather than respondent views. Even though this risk cannot be fully excluded in any study, the complementing data sources including written documentation, technology and system demonstrations, and project meetings were important points of triangulating the results from the interview study. For instance, the videotaped vendor representatives' technology demonstrations were useful for comparing the language they use in everyday technology discourse with that used in our interviews with them.

In terms of data analysis, the empirical categories were generated over time in working with this material in an iterative fashion. Concurring with the hermeneutic circle (Klein and Myers 1999), initial conceptions based on literature reviews and collaborative project planning were used to develop initial semi-structured interview protocols and the basic set of complementary data sources. With an increased understanding of the setting in the course of collecting the material, these conceptions were refined to better reflect the work practices existing and emerging with the use of the studied technologies. Over such cycles of deepened insight generated in working with the material, our analysis was gradually geared towards the role of sensor technology in boundary-spanning practices.

5 Findings

This section of the paper outlines an interpretation of the role of sensor technology in the boundary-spanning processes unfolding in the case organizations. A closer description of the organizational usage of sensor technology is followed by an attempt to make sense of its role in boundary-spanning.

5.1 The dispatcher as boundary spanner

Dispatchers are the social hub between stationary and mobile contexts in transport organizations. Using mobile order management systems and mobile phones, dispatchers typically coordinate the mobile resources in that they distribute customer assignments to specific drivers. The practice of such assignment involves consideration of available fleet capacity, driver locations, driver work schedules, transportation legislation and regulation, as well as environmental care. In managing this complex array of issues, the daily work of dispatchers involves considerable interaction with a range of actors including management, customers, drivers, and others. As commented by dispatchers at case organizations A and C:

Express deliveries are always special cases. It is phone conversations and sometimes I write on the computer simultaneously and sometimes I write notes first. It depends on the customer because some are confused and then it is easier to take notes and transfer it into the system in your own time. Express delivery customers are always in a hurry. They like to give the information in two seconds and hang up.

Sometimes drivers get fewer goods than specified, or more for that matter. He has to communicate that and check if he can load it. If the driver has not yet got the full load specification he doesn't know if he has space enough at the next stop, which causes problems too. […] We [dispatchers] help each other out. You listen and cooperate. If someone calls me who has talked to someone else earlier, I have to know what was said to be able to answer. So you have to be attentive to what is going on all the time. It might sound messy, and it is. It is a messy world we live in.

Dispatchers also monitor and evaluate mobile fieldwork (*i.e.*, operational performance of drivers and vehicles, as well as load capacity utilization); this is done as to improve efficiency through corrective measures at the tactical level. A dispatcher commented:

He [one of the dispatchers] goes through all assignments performed throughout the day. He checks them for any inconsistencies before sending the information on to management. Every month he collects fuel lists and calculates average consumption.

Generally, being a competent dispatcher requires a thorough understanding of the mobile context in the midst of time-critical decision-making. Such understanding is typically displayed in the capacity to enact situated knowledge through the routinely monitoring of the ongoing flow of assignments, driver interaction, management reporting, performance monitoring, and so on.

With the introduction of sensor technology providing measures such as fuel consumption, goods temperature, and position, the transport organizations envisioned new and more time-effective boundary-spanning processes that would help them handle the increased pressures from global competition. In what follows, we take a closer look at four instances of mediating boundary-spanning through ubiquitous computing technologies. Concurring with prevailing notions of anytime-anywhere computing, the introduction of such technologies in the case organizations was associated with a number of hopes related to timeliness and contextual richness of information. As our findings show, they still struggle with making sensor technologies part of the ongoing stream of experience of transport practice.

5.2 Case A

Case organization A confronted problems related to the use of ubiquitous computing technologies in their boundary-spanning processes. At the time of our study, case organization A had employed a mobile system from Barkfors Fleet to optimize their mobile resource allocation. Utilizing GPS technology, dispatchers were able to continuously pinpoint the location of individual trucks on a dynamically updated map representation of the aggregated mobile context. The dispatchers were to gain knowledge of the mobile work context to inform timely order management. The CEO pointed out that dispatchers would no longer have to rely on extensive verbal negotiations with drivers to transfer information from the mobile context to their own, thus speeding up the allocation process:

Then we decide who gets which assignments and send them on to the vehicle that will do the job. The driver who gets it [the assignment] decides if he accepts it or not. And when it is done, he sends a confirmation.

However, there was more to the mobile context than positioning. With the new system, drivers had the option to decline a given assignment from the dispatcher. According to dispatchers, such organizing mechanisms would diminish the perceived utility of a sensor fed representation of the mobile work context:

We question their option to decline. Now you have to call them all the time and ask: 'Why did you decline? What are you going to drive instead? What have you got that we do not know about?' And then we have lost the whole point.

In essence, the introduction of a sensor fed stationary representation of the mobile context illuminated a more complex negotiation process. As the perceived efficiency gains of the system were endangered, dispatchers wanted the interpretation found in the stationary systems representation to enforce their organizing logic and deprive the mobile actors the opportunity to engage in communication and thus collective boundary-spanning. The emphasis on the stationary representation was also evident with the vendor of the transport planning system:

What we are targeting [with our system] is actually all that is going on in the office. We have little control of what goes on in the vehicles. […] Of course, they [the customers] ask us what we find appropriate for them to have in the vehicles, but we do not really care.

Even though the sensor technology acquiring the context data was integrated with the stationary system, the representations were in effect still separated. The utilization of sensor technology was essentially subject to the prior understanding of work practice embedded into the design of the stationary system. Essentially, the sensor data was meant to replace much of the ongoing negotiation between dispatchers and drivers. Thus, the data was not intended to facilitate boundary-spanning; rather it was intended to solve a predefined allocation problem by disregarding other means of gaining knowledge of the mobile context. This clashed with the current work practice of drivers and dispatchers alike.

5.3 CASE B

Case organization B wanted to increase their knowledge of the mobile activities performed by the organization. Comprising embedded vehicle sensors, driver feedback, and stationary reporting tools, Vehco's CoDriver system was therefore implemented in order to understand and improve driver performance. A central objective with the introduction of this technology was to facilitate knowledge creating boundary-spanning between the mobile context and the stationary. More specifically, the system recorded and displayed real time fuel consumption and speed metrics from the trucks. For the purpose of reducing fuel consumption, dispatchers were to utilize these measures to monitor and improve the driving skills of drivers. However, as pointed out by a dispatcher, this objective was hard to satisfy; while the collection of data was satisfactory, the meaning and utility of that data was less straight forward:

I have got the follow up figured out fairly well. The parameters are ready made. The fuel consumption and distance driven; you cannot change that. But to make a good presentation to drivers who are actually using the system…

The fuel consumption metrics was a simplification of driving behavior that was perilous to draw conclusions from. In fact, the dispatchers' interpretation of the sensor fed representation of the mobile context did not in itself provide an explanation:

Of course, driving badly… They can just say 'I loaded 30 tonnes more than you did'. And there are some circumstances too that make you consume fuel.

While the sensor fed representations were to generate detailed knowledge of the mobile context, the divergent frames of dispatchers and drivers required the interpretation of sensor data to be negotiated. With regard to the complexities involved in understanding the mobile context, its representation was felt limited. Even though the system supported the timely acquisition of environmental data, it was not an easy task for dispatchers to create a shared understanding of the mobile practice together with the drivers. In effect, whereas the representation was expected to stimulate the boundary-spanning of co existing contexts, it could at most serve as a starting point in negotiating the meaning of the mobile setting.

Considering the existence of divergent frames, it might be noted that data that could enrich the dispatcher's frame existed within the organization. However, data that could possibly enable a more useful interpretation of the immediate situation of drivers was scattered in several other applications of the computing environment. The following quotation from the vendor of the sensor technologies employed by the organization provides a perspective on the reason for this fragmentation:

We want to sell our stuff. We have got a good solution that works very well. Another vendor says 'buy our solution'. The transport organization then says that we have got one solution for this need and another for that.

From the organization's view, the sensor data was envisioned as an enabler for time efficient management of fuel consumption. In this way, the newfound data was meant to stimulate boundary-spanning between mobile and stationary contexts. However, being designed to be utilized in a predefined fashion, the digital traces found in the systems were deemed limited with regards to meaning creation across contexts.

5.4 CASE C

As early as in the mid-90s, case organization C pioneered Volvo's Dynafleet system for order management and messaging, as well as vehicle and driver performance management. With a fleet consisting of 100 vehicles, C management felt that the communication between dispatchers and drivers also needed to be mediated through other media than mobile phones. It was perceived that the everyday practice of allocating assignments involved too much redundancy and mixed messages, ultimately resulting in both high costs and customer dissatisfaction. Over the years, the order management functionality of the system has essentially met the initial expectations, especially after that Dynafleet was integrated with stationary systems. The CEO commented:

Well, the main advantage is that we save a lot on reduced telephone costs. And reliability. You can be sure that you actually sent the assignment to the driver. Before [the integration of Dynafleet and the stationary systems] you had to record the assignment twice. You received a customer order and entered it once more when sending it to the driver through the Dynafleet system […] Now, it is done instantly. You save a lot of time.

The system also included vehicle sensor-fed functionality for driver and vehicle performance monitoring. At the time of this study, case organization C was dissatisfied with the sensor technologies involved. The CEO conveyed dissatisfaction with the context data provided:

When he [the driver] stops to load or deliver, it is not included in the system today… what kind of stop it is. Since the contract is designed to consider miles driven, hours away, stops, and allowance. If they could get that too… I can see all the stops, but why he stops? He might just be on a break.

As illustrated by the quotation, the CEO felt that receiving vehicle sensor data about occurrences and lengths of stops is necessary but not sufficient for analyzing fleet performance. Since stops are related to pay incentives, allowances, as well as transport legislation, the uncertainty about stop causes was an impediment to straight-forward utilization of the information provided. In fact, rather than supporting competent decision-making, the de-contextualized sensor data risked to cut both ways for actors involved.

Given these and other related difficulties, the sensor-fed functionality of Dynafleet was essentially not used at the time of the study. Management was largely at a loss with regard to the sensor information; this was partly due to the fact the technology supplier was unable to present a viable vision of its intended use. Indeed, the vendor focused on time-efficient sensor data capture rather than context. A vendor representative commented:

That is what Dynafleet is all about, to get performance data non-stop. You can see it all the time. And then you can put it into reports in the office. It is a good tool. […] Our focal point has been what we see in the truck

Aside from the multifaceted use contexts found within user organizations, it was clear that the vendor had many use contexts to take into account, both external and internal:

When we centralize it we see internal benefits. Our retailers can get meter readings from the trucks and act proactively and see the benefit of marketing Dynafleet. You can get vehicle data to gauge if you have sold this customer the wrong vehicle. His driving style is completely different from that which it was designed for.

We talk a lot about segmenting external customers. But very much internal as well. We have leasing companies, we have car rentals. When we own a retailer we can produce unique solutions. Telematics will play an important part, especially when we move towards complete reliability responsibility in leasing agreements. How can we ensure this? By plugging in to see how it is feeling or by making sure it notifies us when it is not.

Reflective of its vehicle manufacturer origin, the prime concern of Dynafleet representatives was the acquisition of sensor data for customer relations and product development. The tool perspective echoed in these quotes was apparently at odds with case organization C's agenda. Thus, the use of context data proposed by the design of the acquiring technology was not congruent with the objectives of the user organization. In practice, no meaningful interpretations of the acquired context data could be made. The de-contextualized signals provided through the sensor technology were not interpreted as useful information in their boundary-spanning processes and the organization therefore ceased using them.

5.5 Case D

Case organization D had a clear ambition to integrate sensor, mobile, and stationary computing to facilitate time efficient management by continuously monitoring distance traveled, speed, and fuel consumption. The introduction of the sensor technology was motivated by a need to more accurately gauge the estimated efficiency of vehicles and drivers. Although initially appreciative, they soon experienced shortcomings of the sensor fed representations of the mobile context. In particular, the mobile context was considered to include numerous complex interactions with essentially external conditions. Weather conditions, topology, road conditions, and other parts of long range haulage practice were elusive in terms of overall context interpretation. In some cases, the system representations could render false analyses and potentially badly informed decisions:

It is rather difficult, since there are more things to consider. We include road toll costs. If you choose a small, non-toll, road to save costs, you will most likely cause an increase in fuel consumption instead. All in all, with our kind of traffic, it is not that simple.

The dispatcher was highly skeptical to the practical utility of fully automated computing environments for enabling boundary-spanning. Sensor fed context data was not perceived useful for making context interpretations. Indeed, in conveying this cautiousness, the dispatcher emphasized the complexity of the context surrounding any given mobile worker:

Every trip is a new one. I know some distances by heart nowadays, but other than that, every trip is unique. They have never driven exactly the same way twice.

In view of these problems, the vendor, whose primary business was truck manufacturing, felt that more data would overcome the experienced problems:

There are lots of different things like logistics systems, scales, refrigeration equipment… a virtually endless list. For starters, we concentrate on the low-hanging fruit.

Reflecting the core competence of the vendor, acquisition of context data was its primary concern. To the extent that use of context data was considered, it concerned application areas that could be closely associated with technical engine functionality:

You can also see the percentage of time spent on the green rpm-area, which is also how well you have used the engine. So, it gives you a good explanation [to high fuel consumption]. But it requires someone to help customers interpret these numbers.

The motivation for delivering context information was closely related to the relationship between the user organization and the manufacturer. Indeed, utilizing vehicle sensor data internally was perceived an important part of retaining customers.

We are able to sharpen our services such as service agreements and maintenance if we get vehicle data in. We can become consultants to our customers and help them utilize their vehicles more efficiently… to get a higher utilization and lower costs. That is perhaps the most important aspect from the manufacturer's point of view. It's not about selling computers, but rather about reinforcing customer relations.

Clearly, there existed divergent user and vendor views. While the user organization pinpointed the importance of enriching boundary-spanning through more contextualized aggregations, the vendor seemed to experience this as a problem of adding more parameters to the existing ones.

6 DISCUSSION

Being a time-critical and knowledge-intensive activity, boundary-spanning has been portrayed as the capability of organizations to respond to dynamic change and derive long-term value from context information (Cohen and Levinthal 1990). Indeed, such capability is critical to virtually all organizations involved in any intellectual work comprising knowledge creation and transfer in distributed settings. However, one of the challenges for organizations today is how to tackle the increased heterogeneity of work contexts. Thus, a central concern for IS research and practice is to advance the current understanding of how IT systems can allow such organizations to be sensitive to the contextual settings in which they operate, so that their operations can be attuned to these variations.

Reflecting that IT systems need the capability to sense and respond to changes in the context, IS researchers have recognized that organizations today are increasingly dependent on intelligent environments based on anytime, anywhere computing (March *et al.* 2000; Yoo and Lyytinen 2005). Optimistically forecasted to seamlessly integrate organizations, people, and systems across traditional boundaries, ubiquitous computing has been promoted as the technology for the realm of distributed organizations. While the introduction of ubiquitous computing is likely to blur both physical, social, and temporal boundaries of an organization and its environment (Henfridsson and Lindgren 2005; Lyytinen and Yoo 2002), the major promise of ubiquitous computing in boundary-spanning is the capability to (more or less) automatically acquire a broad range of context information about distributed work activities in real-time.

Whereas sensor technology has been utilized to detect or sense signals of internal conditions or performance in a multitude of industries for decades, there is growing evidence that organizations include such technology in their information environments as to leverage business propositions and increase customer value (Lyytinen and Yoo 2002). Studies reported in Andersson and Lindgren (2005) and Jonsson *et al.* (forthcoming) show that ubiquitous computing environments may grant organizations detailed digital traces of distributed operations through positioning technology, embedded sensor networks, and similar technologies. Indeed, as these accounts indicate, monitoring digital traces offers the possibility of improved processes of boundary-spanning. These two studies document that competitive information and situated adaptation are pressing in the context of ubiquitous computing environments. However, somewhat contrasting the approaches taken in the innovation (see *e.g.*, Malhotra *et al.* 2005) and work practice (see *e.g.*, Levina and Vaast 2005a) literatures, such environments require that these problems are handled simultaneously.

The entanglement of competitive information and situated adaptation problems can be traced to the multi-contextuality of ubiquitous computing environments, *i.e.*, the co-existence of different use contexts (Henfridsson and Lindgren 2005). While the notion of multi-contextuality was originally coined for understanding consumer adoption of personal telematics services, our paper contributes to the boundary-spanning literature with an understanding of what the co-existence of different use contexts means for boundary-spanning practices in industry settings. It illustrates that the introduction of sensor technology in boundary-spanning coincides with changes in the complex relationship between boundaries and technology support:

> **Re-defined boundary understanding:** Configuration of IT-enabled boundary-spanning support such as sensor technology will alter boundary spanners' understanding of their environment. Over time, the technology will re-define the contextual cues with which boundary spanners make sense of remote information. For instance, the introduction of sensor technologies in cases A and B introduced negative side-effects for the mutual sensemaking between dispatchers and drivers. Dispatchers were therefore inclined to introduce work-arounds to compensate for their perceived loss of context understanding. However, it can be expected that continued use of sensor technology in the name of optimization will gradually diminish the former understanding of context and in this sense re-define boundary understanding practices.
>
> **Negotiated boundary practices:** Single organizations will have less control over their boundary-spanning practices as they emerge in inter-organizational relationships. Internal communication channels crossing boundaries are traditionally controlled by the organization. However, the use of sensor technology influences organizational control.

Looking at Case D, the use of sensor technologies for improving the efficiency of vehicles and drivers did not satisfy the contextual precision needed for accurate evaluation and control. In approaching the vendor (and vehicle manufacturer) for negotiating the data collection and interpretation, the transport organization was introduced to other sensor data sources including logistic systems, refrigeration equipment, and so on. Given that such data are controlled and provided by other actors, it is clear that sensor technology-enabled boundary-spanning practices require negotiation with multiple providers.

Blurred boundaries: The distinction between internal and external boundaries becomes less useful. In case C, the vehicle manufacturer providing the Dynafleet system greatly valued the information provided by the sensor technology embedded in the vehicles sold to the transport organization. The information was useful for both customer relations and new product development. However, the same sensor data can be considered internal or external depending of its intended use. When used for customer relations, the information must be considered as external in the sense that it reflects the needs of an external customer. In the case of product development, it can be considered as internal in the sense that the transport organization's fleet of vehicles basically works as a test environment. In sum, the fact that sensor data generated in one organizational unit is used in multiple organizations or organizational units for different operational and strategic purposes blurs boundaries in an ambiguous way.

As these consequences are most likely not unique to the transport context, we believe that they have important theoretical and practical implications for the utilization of different types of IT systems as support for boundary-spanning in distributed settings. On the theoretical side, the three consequences summarized above illustrate the dependency between information gathering activities for gaining competitive advantage and sensemaking activities intended to situate de-contextualized information in local work practices. Traditionally, these issues have largely been treated separately in the extant literature on boundary-spanning. However, this dependency calls for integrative approaches for theorizing and rethinking linkages between IT systems and boundary-spanning practices. Relating the notion of multi-contextuality (Henfridsson and Lindgren 2005) to the innovation (see *e.g.,* Cohen and Levinthal 1990; Friedman and Podolny 1992; Leifer and Delbecq 1976; Tushman and Scanlan 1981) and work practice (see *e.g.,* Balogun *et al.* 2005; Carlile 2002; Pawlowski and Robey 2004) literatures, this paper extends the current understanding of boundary-spanning in IS by taking the first steps to such theory development.

In terms of practical implications, our findings offer insights about side-effects surrounding attempts to seamlessly integrate organizations, people, and systems. Since distributed use contexts are typically separated by a multiplicity of boundaries within and between organizations, the consequences identified provide evidence for the idea that support systems for boundary-spanning need to reflect these boundaries. However, the issue of how to avoid the pitfall of configuring boundless elements in ubiquitous computing environments is a challenge in itself. Collaborative industrial-academic research projects are therefore encouraged to produce guidance for how the infusion of seams between elements in large-scale complex socio-technical systems may allow for bounded interactions in distributed settings.

7 Conclusion

This paper contributes to the boundary-spanning literature with an understanding of what multi-contextuality means for boundary-spanning practices in industry settings. Building on an interpretive case study of Swedish transport organizations, the paper has presented an analysis of organizational consequences of competitive information and situated adaptation problems in ubiquitous computing environments. Lying at the heart of the complex relationship between boundaries and technology support, the multi-contextuality of ubiquitous computing environments has important theoretical and practical implications for implementation and use of IT systems in boundary-spanning.

Our study suggests that the successful deployment of IT systems in boundary-spanning will rely on complex interactions involving multiple organizational actors, including technology suppliers, blurring the boundaries of the organization and in effect complicating the acquisition and use of context information. Therefore, integrative approaches are needed that combine insights from the innovation and work practice literatures to theorize the multi-contextual nature of technology in heterogeneous and competitive boundary-spanning practices.

8 References

Andersson, M. & Lindgren, R. (2005) The mobile-stationary divide in ubiquitous computing environments: lessons from the transport industry. *Information Systems Management,* 22(4), 65-79.

Balogun, J., Gleadle, P., Hope Hailey, V. & Wilmott, H. (2005) Managing change across boundaries: boundary-shaking practices. *British Journal of Management*, 16, 261-278.

Carlile, P. R. (2002) A pragmatic view of knowledge and boundaries: boundary objects in new product development. *Organization Science,* 13(4), 442-455.

Choudhury, V. & Sampler, J. L. (1997) Information specificity and environmental scanning: an economic perspective. *MIS Quarterly*, 1, 25-53.

Cohen, M. D. & Levinthal, D. A. (1990) Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128-152.

Fano, A. & Gershman, A. (2002) The future of business services in the age of ubiquitous computing. *Communication of the ACM*, 45(12), 83-87.

Friedman, R. A. & Podolny, J. (1992) Differentiation of boundary-spanning roles: labor negotiations and implications for role conflict. *Administrative Science Quarterly*, 37, 28-47.

Giddens, A. (1976) *New Rules of Sociological Method*, New York: Basic Books.

Grudin, J. (2002) Group dynamics and ubiquitous computing. Communications of the ACM, 45(12), 74-78.

Hayes, N. (2001) Boundless and bounded interactions in the knowledge work process: the role of groupware technologies*. Information and Organization*, 11, 79-101.

Henfridsson, O. & Lindgren, R. (2005) Multi-contextuality in ubiquitous computing: investigating the car case through action research. *Information and Organization*, 15(2), 95-124.

Jessup, L. M. & Robey, D. (2002) The relevance of social issues in ubiquitous computing environments. *Communications of the ACM*, 45(12), 88-91.

Jonsson, K., Westergren, U. H. & Holmström, J. (forthcoming) Technologies for value creation: an exploration of ubiquitous computing in business networks. Accepted for publication in *Information Systems Journal*.

Kellogg, K. C., Orlikowski, W. J. & Yates, J. (2006) Life in the trading zone: structuring coordination across boundaries in postbureaucratic organizations. *Organization Science*, 17(1), 22-44.

Klein, H. K. & Myers, M. D. (1999) A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS Quarterly*, 23(1), 67-93.

Kogut, B. & Zander, U. (1992) Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science*, 3(3), 383-397.

Leifer, R. & Delbecq, A. (1978) Organizational/environmental interchange: a model of boundary-spanning activity. *Academy of Management Review*, 3, 40-50.

Levina, N. & Vaast, E. (2005a) The emergence of boundary-spanning competence in practice: implications for implementation and use of information systems. *MIS Quarterly,* 29(2), 335-363.

Levina, N. & Vaast, E. (2005b) Turning a community into a market: a practice perspective on information technology use in boundary-spanning. *Journal of Management Information Systems*, 22(4), 13-37.

Lyytinen, K. & Yoo, Y. (2002) Research commentary: the next wave of nomadic computing. *Information Systems Research,* 13(4), 377-388.

Malhotra, A., Gosain, S. & El Sawy, O. A. (2005) Absorptive capacity configurations in supply chains: gearing for partner-enabled market knowledge creation. *MIS Quarterly*, 29(1), 145-187.

March, S., Hevner, A. & Ram, S. (2000). Research commentary: an agenda for information technology research in heterogeneous and distributed environments. *Information Systems Research*, 11(4), 327-341.

Morash, E. A., Dröge, C. & Vickery, S. (1996) Boundary-spanning interfaces between logistics, production, marketing and new product development. *International Journal of Physical Distribution & Logistics*, 27(5/6), 350-369.

Orlikowski, W. (2002) Knowing in practice: enacting a collective capability in distributed organizing. *Organization Science,* 13 (3), 249-273.

Orlikowski, W. J. & Baroudi, J. J. (1991) Studying information technology in organizations: research approaches and assumptions. *Information Systems Research*, 2(1), 1-28.

Pawlowski, S. D. & Robey, D. (2004) Bridging user organizations: knowledge brokering and the work of information technology professionals. *MIS Quarterly*, 28(4), 645-672.

Rosenkopf, L. & Nerkar, A. (2001) Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry. *Strategic Management Journal*, 22, 287-306.

Russ, G. S., Galang, M. C. & Ferris, G. R. (1998) Power and influence of the human resources function through boundary-spanning and information management. *Human Resource Management Review,* 8(2), 125-148.

Santos, F. M. & Eisenhardt, K. M. (2005) Organizational boundaries and theories of organization. *Organization Science*, 16(5), 491-508.

Schultze, U. & Orlikowski, W. J. (2004) A practice perspective on technology-mediated network relations: the use of Internet-based self-serve technologies. *Information Systems Research*, 15(1), 87-106.

Scott, W. R. (1992) *Organizations – Rational, Natural, and Open systems*, (3 ed.). Englewood Cliffs, New Jersey: Prentice-Hall.

Star, S. L. (1989) The Structure of Ill-Structured Solutions: Heterogeneous Problem-Solving, Boundary Objects and Distributed Artificial Intelligence. In: *Readings in distributed artificial intelligence*. Huhns, M. & Gasser, L. (eds.), pp. 37-54. Morgan Kauffman, Menlo Park, CA.

Tushman, M. L. (1977) Special boundary roles in the innovation process. *Administrative Science Quarterly*, 22, 587-605.

Tushman, M. L. & Scanlan, T. J. (1981) Characteristics and external orientations of boundary-spanning individuals. *Academy of Management Journal*, 24(1), 83-98.

Van Maanen, J. (1979) The fact of fiction in organizational ethnography. *Administrative Science Quarterly*, 24(4), 539-550.

Voydanoff, P. (2005) Consequences of boundary-spanning demands and resources for work-to-family conflict and perceived Stress. *Journal of Occupational Health Psychology*, 10(4), 491-503.

Walsham, G. (1995) Interpretive case studies in IS research: nature and method. *European Journal of Information Systems*, 4, 74-81.

Yoo, Y. & Lyytinen, K. (2005) Social impacts of ubiquitous computing: exploring critical interactions between mobility, context and technology - a special issue for *Information and Organization. Information and Organization*, 15(2), 91-94.

FOURTH PAPER

4 LEVERAGING UBIQUITOUS COMPUTING ENVIRONMENTS THROUGH A MOBILE-STATIONARY INTERFACE

MAGNUS ANDERSSON

ABSTRACT

Ubiquitous computing environments grant organizations a multitude of dynamic digital traces composed of context signals emanating from embedded and mobile components. Indeed, such signals can enhance organizations' understanding of the different contexts in which they act. However, previous IS literature highlights that the utility of context signals is frequently hampered by a priori interpretations of context embodied within the acquiring technologies themselves. Building on an 18-month action research study involving researchers, system vendors, and Swedish transport organizations, this paper reports an attempt to rearrange an industry-wide assemblage of stationary, mobile, and embedded technologies. For the purpose of facilitating cross-organizational access to reinterpretable digital traces of context data, this was done by inscribing the notion of seamfulness in an open vertical standard interface as a means to shift the locus of interpretation of context data. With the objective to extend the current understanding of how organizations can derive value from context data, the paper contributes with an assessment of existing design requirements for context-aware ecosystems. This assessment reveals the complexity of accomplishing links between socio-technical elements in ubiquitous computing environments.

Keywords: Ubiquitous computing, context data, open vertical standard interface

1 INTRODUCTION

Following Weiser's vision (1991), the miniaturization of computing devices and developments in mobile and wireless communication technologies have steadily increased. In fact, the notion of computing anytime, anywhere has been evident in the continuous diffusion of mobile and embedded technologies for a number of years (Lyytinen and Yoo 2002a; March et al. 2000). Reflecting on why ubiquitous technology is optimistically forecasted, Yoo and Lyytinen (2005) assert that organizations today are increasingly dependent on intelligent environments based on anytime, anywhere computing. Indeed, with ubiquitous technology businesses are no longer tied to certain time-constraints and spaces (Jessup and Robey 2002). Transport is a useful example of a business area where such technology could enhance complex processes. As an illustration, ubiquitous computing technology may influence the way logistic partners reshape and optimize their integrated supply chains by recognizing alterations in inventory levels, market demands, and transport constraints.

However, as ubiquitous technologies appear outside of laboratories, organizations need to adapt their organizing logic to the increased socio-technical complexity of computing environments involving mobile, embedded, and stationary elements (Sambamurthy and Zmud 2000). While there are unanswered questions about the implications of ubiquitous technology on value-creation in business settings, integration of such technology in distributed organizational environments is becoming increasingly commonplace (Fano and Gershman 2002), thus enabling studies of real world usage (e.g., Andersson and Lindgren 2005; Jonsson et al. forthcoming; Lindgren et al. forthcoming).

Context-awareness is an essential notion in research on ubiquitous computing (Dey et al. 2001). According to Abowd and Mynatt (2000), context-awareness refers to the capability of systems to recognize and adapt to the multifaceted context of their use. In recent years, seamless computing has been used to denote the vision of fully transparent, integrated, and adapted system support (Henfridsson and Lindgren 2005). For the purpose of freeing users from the manual adjustments typically required, an often stated goal is that ubiquitous computing services should dynamically utilize underlying infrastructure resources to operate seamlessly over many contexts (Dey 2001). However, as recognized in the IS literature, there are a number of socio-technical challenges associated with integration of infrastructure resources as to provide a ubiquitous computational solution to a client's requirements (Andersson and Lindgren 2005; Lyytinen and Yoo 2002a).

Studying distributed computing infrastructures intended to facilitate efficient and seamless integration of people and systems in transport organizations, Andersson and Lindgren (2005) show that mobile systems are not simple conversions of stationary systems into a different environment, but require comprehensive integration between mobile, embedded, and stationary components. In fact, the study illustrates that captured contextual parameters are subject to interpretation by various individuals or organizations dependant on their use (cf. Dourish 2004). However, technology vendors were effectively omitting this important characteristic in attempting to design seamless environments delivering their a priori interpretations of context.

As Andersson and Lindgren argue, there are at least two lessons learned from the transport industry that are also applicable to the general design of ubiquitous computing environments. First, organizations need to understand and agree on the meaning and value of context data as part of their strategy to integrate mobile, embedded, and stationary technology components. Second, well-functioning best-of-breed mobile-stationary assemblages require a unification of a wide variety of technologies and competencies originating from multiple vendors organizations, having different strategies guiding their conduct influenced by their perceived core competence and installed base of systems and user organizations. Given that contextual representation utilizing ubiquitous computing technology to deliver value-creating business information has been found highly problematic, Lindgren et al. (forthcoming) call for academic-industrial research projects that produce guidance for how to erect ubiquitous computing environments so that the issue of inflexible utilization of mobile and embedded technologies can be resolved.

While the multi-contextual nature of ubiquitous computing environments requires hybrid, best-of-breed, and adaptive computing infrastructures providing scalability, flexibility, and openness to emerging mobile and embedded technologies, there are few studies of practical attempts to integrate increasingly heterogeneous stationary and distributed technological components. Seeking to address this gap in the IS literature, the research presented here utilizes action research (Baskerville and Wood-Harper 1996) to intervene in a real world problem situation. On the basis of an 18-month action research study involving researchers, system vendors, and Swedish transport organizations, this paper reports a cooperative design attempt to rearrange an industry-wide assemblage of stationary, mobile, and embedded technologies. For the purpose of facilitating cross-organizational access to reinterpretable digital traces of context data, this was accomplished by inscribing the notion of seamfulness (Chalmers and Galani 2004) in an open vertical standard interface as a means to shift the locus of interpretation of context data in ubiquitous computing environments (UCE). Given the action research agenda to counter the interpretational inflexibility of the current seamless approach to UCE (Andersson and Lindgren 2005), the goal was to increase user organizations' capacity to interpret context as opposed to relying on a predefined representation as visualized by individual component system vendors. With the objective to extend the current understanding of how organizations can derive value from context data, the paper contributes with an assessment of extant general design requirements for context-aware ecosystems. This assessment reveals the complexity of accomplishing links between socio-technical elements in ubiquitous computing environments.

The paper proceeds as follows. First, received theory on ubiquitous computing environments and the associated problem of inflexible interpretations of context data is reviewed. This is followed by a presentation of transport industry UCE and the working hypothesis guiding this research effort. Thereafter, the research context and details about the method applied is described. Then, the results from the study are presented. In the concluding sections, the viability of extant general design requirements for context-aware ecosystems is assessed and the findings linked to further research opportunities.

2 Theoretical Background

The concept of ubiquitous computing environments is increasingly studied in IS literature (Andersson and Lindgren 2005; Henfridsson and Lindgren 2005; Jonsson et al. forthcoming; Lindgren et al. forthcoming). Lyytinen and Yoo (2002a, p. 378) describe a ubiquitous computing environment as "… a heterogeneous assemblage of interconnected technological and organizational elements, which enables the physical and social mobility of computing and communication services between organizational actors both within and across organizational borders". Akin to Weiser's (1991) vision of computing embedded in people's natural movements and interactions with their physical and social environment, Lyytinen and Yoo (2002b, p. 63) recognize that "ubiquitous computing will help organize and mediate social interactions wherever and whenever these situations might occur". Similarly, Grudin (2002) asserts that ubiquitous computing promises to enable efforts to record and archive digital traces of socio-technical activities and interactions in distributed environments over time for real time or subsequent review or viewing by those not present. Once stored in a repository and shared via networks, digital traces can enhance organizations' understanding and knowing of the contexts in which they act (Jessup and Robey 2002). Indeed, capable of leveraging digital representations of context across time and place through advanced sensor technology, ubiquitous computing can be seen as a critical technology in the realm of distributed organizations.

Ubiquitous computing environments require an extensive infrastructure (Lyytinen and Yoo 2002a), thus incorporating a wide range of associated properties. In practical terms, this infrastructure typically includes components such as wireless communication technologies, sensors, and various computing devices. However, the notion of infrastructure takes into account not only the technologies involved, but also the heterogeneous actors involved in realizing and using it (Star and Ruhleder 1996). Thus, an infrastructure is essentially a blend of technical and social elements.

Reviewing the information infrastructure literature, Hanseth and Lyytinen (2004) define three general characteristics of information infrastructures. First, as opposed to traditional information systems, information infrastructures have no specific purpose other than a very general idea of offering information related services to a single or group of communities. However, infrastructures can be designed to support more specified purposes (Hanseth and Lundberg 2001). Second, information infrastructures evolve continuously and unexpectedly because they have no fixed boundaries. In fact, the installed base, i.e., the presently available information infrastructure, will determine the possibilities for further extensions. Essentially, this means that no single information infrastructure is built from scratch. Rather, the installed base restricts the ways in which information infrastructures can evolve (Star and Ruhleder 1996). As a consequence, factors other than technical superiority will likely play a crucial part in determining the way in which these environments develop. Third, information infrastructures consist of highly heterogeneous technological and social components with complex dependencies. Therefore, these must be managed through well defined interfaces between constituent layers. In practical terms, interfaces, gateways, and standards bind an information infrastructure together (Hanseth 2001) and changes require the negotiation and translation of interests of many different actors (Hanseth and Monteiro 1997; Yoo et al. 2005).

A central driver for organizational diffusion of ubiquitous technologies is context-aware computing. A practical implication of the accelerating spread of embedded technology, such as RFID, is the decreasing cost of data input. In this sense, the expanding pervasiveness of the digital world is rapidly closing the gap to the physical (Jonsson et al. forthcoming). Indeed, the associated services have some important implications for the design of ubiquitous computing environments. First, utilizing underlying embedded technologies, services in ubiquitous computing environment should be capable of dynamically recognizing the multifaceted context of their use and take appropriate action when it changes (Dey 2001). Second, services should be able to seamlessly access the underlying infrastructure, attaining the resources necessary for completing the user’s task without the need for user manipulation (Abowd and Mynatt 2000).

However, interpretation of the data gathered is frequently an ambiguous process, highly dependent on the situation at hand (Dourish 2004). Moreover, one physical sensor can be utilized by a number of services for equally different purposes. Simply adding more sensors would never entirely eliminate the problem of interpreting complex contexts as the main issue is the a priori interpretation forming the basis of computational representation of context. However, rather than designing ubiquitous computing seamlessly, encapsulating an a priori interpretation of context and hiding the constituent parts from user interaction, a seamful design as suggested by Chalmers and Galani (2004) aims at exposing the constituent parts of the ubiquitous computing environment to allow for a more comprehensive and user-centered interpretation when necessary.

As Banavar et al. (2005) note, open large scale ubiquitous computing environments should consist of separate layers performing adaptation, aggregation, and analysis of data as well as applications reacting to changes in context. Ideally, this will create incentives for separate producers of context data, middleware, and applications, thus enabling organizations to construct flexible ubiquitous computing environments capable of delivering tailored representations of context (Banavar et al. 2005). However, in separating these areas of concern, joining the diverse sources of context data will require well defined seams. Indeed, a computing environment able to produce such reinterpretable representations of context must be highly malleable in that constituent parts can be dynamically combined to inform the task at hand. In an organizational setting, a ubiquitous computing environment should be capable of facilitating a wide range of such tasks, capturing representations of experiences from one context and projecting them to another (Abowd and Mynatt 2000). Depending on context and intended use, services need access to the various constituent technologies of the environment to produce an adequate representation. Research on such context aware computing environments includes prototyping of services in real world settings (Henfridsson and Lindgren 2005; Olsson and Henfridsson 2005) and novel architectures (Banavar et al. 2005; Dey et al. 2001).

Using the notion of “context ecosystem”, Banavar et al. (2005) focus on the nonexistent division of labor among providers of context-aware computing. They note that vendors typically supply and control both low level data capture hardware and high level analysis software. The resulting situation is one in which limited custom solutions exist. As the context representations are the result of vendors’ a priori interpretation encapsulated in services, the representation are inflexible in terms of reuse for alternate interpretations. In sum, an ideal ubiquitous computing environment including sources of context data should meet a number of design requirements pertaining to the locus of interpretation (Banavar et al. 2005). First, a ubiquitous computing environment must enable the exchange of context information across organizational entities. Second, a ubiquitous computing environment must combine data from available computing resources to make context data interpretable and exploitable in multiple uses. Third, a ubiquitous computing environment must access a multiplicity of critical sources of context data from a potentially diverse set of providers to enable dynamic representations of context. Fourth, a ubiquitous computing environment must be able to dynamically discover and utilize new instances of context data sources. Fifth, a ubiquitous computing environment must allow new kinds of context data to be added. The next section explores road transport UCE.

3 UCE IN THE ROAD TRANSPORT INDUSTRY

Transport organizations typically consist of both mobile field operations and stationary headquarters elements. UCE intended to meet IT requirements of transport organizations contain elements of stationary, mobile as well as embedded computing (Andersson and Lindgren 2005). The interwoven technological realms are commercial telematics (in-vehicle sensors and communication systems), stationary transport planning systems, and administrative enterprise systems (Roy 2001). The embedded vehicle technologies serve different purposes for different users. For a driver, services utilize vehicle data to display feedback metrics on the performance of the vehicle raising awareness of, for example, fuel consumption. Similarly, the resulting persistent digital traces of mobile fieldwork are used by management as a tool to analyze fleet performance from a distance. The stationary planning systems are used by dispatchers to coordinate assignments, but also to communicate associated information to drivers using integrated mobile communication technologies. In addition, information from positioning technologies such as GPS facilitates this process and is also offered as a customer service while simultaneously enabling in-vehicle navigation services. Indeed, computing components such as those described above are vital for the inter-organizational coordination required in the complex interwoven and time critical transport industry. Finally, vendors of embedded technologies collecting data use that data for internal purposes of physical product development and associated services (Jonsson et al. forthcoming; Lindgren et al. forthcoming). Thus, a UCE span multiple inter and intra organizational contexts, each of which has distinct requirements of use.

As Andersson and Lindgren (2005) note, a UCE ideally endows the organization with a dynamic repository of context data captured by embedded technologies. Combined with representations held by stationary systems, such repositories may create a digital trace of mobile work. However, utilizing this trace means grappling with a heterogeneous set of technologies and associated organizational actors. The vendor domain of UCE has been characterized by a large number of actors with diverse incentives. However, the distinction between vendors of stationary, mobile, and embedded technology is an abstraction. In reality, most vendors seek to offer both stationary and mobile elements of UCE. As an illustration, the vendors supplying mobile and embedded technology for capturing vehicle data generally bundle it with stationary analysis software. Services are based on the use of context data as intended by the vendors, meaning that there is little or no possibility to add new sources of context to derive new representations catering additional needs. As a consequence, representations of mobile work embedded in these arrangements are closed in that one vendor (or limited alliance) defines the interpretation of a given subset of the digital trace in a UCE with little influence from the user organization. Indeed, the user organizations in turn must deal with a number of such seamless integrations to acquire comprehensive UCE. This effectively constitutes a mobile-stationary divide, limiting the utilization of mobile, embedded, and stationary computing to the context representations envisioned by a fragmented set of suppliers of these technologies (Andersson and Lindgren 2005; Lindgren et al. forthcoming).

Applying the notion of seamfulness (Chalmers and Galani 2004) to UCE in the transport domain suggests creating a more adaptive ubiquitous computing environment in which context aggregation and reinterpretation is enabled through a number of well defined seams. In a complex information infrastructure, these seams can be seen as interfaces between defined layers of the environment. Some examples of existing lower level standardized interfaces applicable to UCE in the road transport industry are the fleet management system interface, FMS, (http://www.fms-standard.com) to embedded vehicle systems and generic wireless communication protocols. However, previous research has clearly shown the need to introduce further links into currently fragmented computing environments, thus providing user organizations a means to avoid the impenetrable seamless representations embodied in “vertical” solutions from single vendors or limited strategic alliances. Such links should ideally tie the mobile, embedded, and stationary technologies as well as the user organization together. Indeed, transport UCE case provides a viable venue for exploring socio-technical issues surrounding the construction of ubiquitous computing environment embodying flexible means of context data interpretation.

Banavar et al. (2005) suggest that open ubiquitous computing environments should support a division of labor by separating context data acquisition from analysis. In what follows, their general design requirements for context-aware ecosystems are utilized in the transport setting. First, A UCE must enable exchange of context information across organizational entities. This requires open standardized models and context data formats shared by mobile, stationary, and embedded transport technologies. Second, a UCE must combine data from available computing resources to make context data interpretable and exploitable in multiple uses. This requires that vendors of different technologies engage in gaining a common understanding of potential uses of context data. Third, a UCE must enable dynamic representations of context. This requires access to a multiplicity of critical sources of context data from a potentially diverse set of providers including vendors of embedded and mobile transport technologies. Fourth, a UCE must be able to dynamically discover and utilize new instances of context data sources. This requires that vendors of different embedded, mobile, and stationary transport technologies incorporate a plug-and-play interoperability strategy. Fifth, a UCE must allow new kinds of context data to be added. This requires delivery of sets of context data that transport system vendors can easily adopt.

However, it is not clear how to realize a separation of context data acquisition and analysis. In particular, it is likely that the consequences for the partaking vendor collective will be profound. Indeed, aligning with other actors whose interests and capabilities may not be consistent with their own may influence the companies' internal strategies and operations and ultimately their identities (Yoo et al. 2005). By utilizing extant general design requirements for context-aware ecosystems in this specific problem situation, this research contributes with an assessment of their viability and links the findings with further research opportunities.

4 METHOD

4.1 RESEARCH SETTING

Road transport is critical for the European economy (Berg Insight 2006). Each day, EU transport industries and services deal with 15 million courier, express, and parcel shipments, carrying a total of approximately 50 million tones of goods. Of all goods moved within EU, commercial vehicles transport 44 percent. With regard to EU inland freight transport, trucks move 74 percent. In 2002, the total volume of road transports undertaken by EU registered haulers was 1,347 billion tones-kilometers. While national transport accounted for the vast majority of the total road transport volume, international transport made up some 20 percent.

As a particular type of transport organization, road haulage firms use trucks to transport some type of goods from one place to another. Whereas such firms are similar in that trucks, drivers, and transport activities constitute the core of the business, the road haulage industry sector is far from homogeneous. Typically, business activities, organizational structures, and size vary. In fact, road haulage can be described as a diversified line of business. While local distribution of goods requires loading and unloading several times each day, a significant feature of long distance transports is that it can take days between loading and unloading. Thus, the nature of work differs, ranging from rather static transport activities that can be planned ahead to dynamic situations where assignments must be communicated to the driver during the day.

A number of roles are usually found in a road haulage firm: administrative personnel, dispatcher, driver, management, and vehicle management personnel. Administrative personnel handle invoicing and wages. Dispatchers handle incoming assignments and organize drivers and trucks. Drivers transport goods, which involves loading, unloading, planning routes, driving, and interacting with transport buyers. Managers conduct economic planning and follow-up activities. Vehicle management personnel perform activities such as supervising of fleet status, service time scheduling, and tire changing. However, the borders of these task-related roles are often fluid. In small road haulage firms, the same person can have more than one role or several persons can have a similar role. In larger firms, the personnel are likely to have more specialized roles.

The EU road transport industry sector is characterized by a high proportion of small and micro enterprises (Berg Insight 2006). According to the Swedish Road Haulage Association (representing approximately 11,000 road haulers with some 30,000 vehicles and machines), almost 90 percent of their members operate approximately five vehicles, indicating that most Swedish road haulers are small firms. In the current situation, the Swedish road transport industry sector undergoes changes caused by the EU’s open market. As an example, foreign transport firms have increased their share of transportations, which is a direct result of lower costs in nearby countries such as Denmark, Germany, Netherlands, and Poland. This cost disadvantage has rendered to minimal profitability margins for small and independent road haulage firms. In this situation, contractors of haulers such as Danzas and Schenker have strengthened their market position.

Like counterparts in EU and North America, Swedish road haulage firms are implementing different types of IT support to improve their competitiveness. Such IT support includes a wide range of applications that can be categorized into three distinct classes (See Table 1).

Class	*Infrastructure*	*Functionality*
Mobile systems: This class of IT support is aimed at improving the efficiency of mobile workers	• Nomadic devices (portable terminals) integrated with vehicle electronics in cockpit • Vehicle-mounted communication terminals (share platform with vehicle-centric applications)	• Communication between stationary personnel and mobile workers • Information about mobile workers' positions • Remote access to stationary enterprise systems • Text messaging
Transport systems: This class of IT support is aimed at improving the efficiency in transportation	• Geographical information systems • Transport applications integrated with ERP software	• Event-triggered alerts and geo-fencing • Geo-positioning • Navigation and route optimization • Order management • Route optimization software • Vehicle, cargo, and goods monitoring and tracking
Embedded systems: This class of IT support is aimed at improving the efficiency of both vehicle and driver	• Active ignition sensing software • Barcode scanners • CAN-bus • Electronic trip recording software • GPS receiver • RFID technology	• Breaking and shifting behavior analysis • Driving and stopping times tracking • Driver working time analysis • Fuel consumption and trip distances monitoring • Maintenance planning • Navigation software

Table 1: Classes of IT support (Adapted from Berg Insight 2006)

As Williams and Frolick (2001) recognize, the size of transport organizations is a critical factor in that it determines the amount of resources for procuring and administrating IT support. Being small firms, Swedish road haulers rarely can afford to develop a custom built system as to secure technical advantage. Rather, they are typically forced to consider the various off-the-shelf solutions available. Indeed, the wide variety of business activities in road haulage firms makes this choice complicated. In the current situation, unresolved technical issues exist with regard to IT support for transport firms. Such geographically dispersed IT support is technically complex in terms of the number of portable devices, embedded applications, databases, and systems involved, requiring a common platform of protocols and data standards to ensure systems interoperability and enable the integration of a plethora of distributed technologies. As Andersson and Lindgren (2005) note, this situation can be traced to rivalry and competition between various technological solutions, originating from diverse innovation regimes (Godoe 2000).

4.2 Research Design

Given the objective of resolving the interpretational inflexibility of the current seamless approach to UCE, action research is a suitable mode of inquiry. As Baskerville and Wood-Harper (1996) note, action research is a research method that stresses the theoretically guided intervention into a practical problem setting in order to produce new knowledge. Action research allows the researcher to test a working hypothesis about the phenomenon of interest by implementing and assessing change in a real-world setting. By analyzing discrepancies between the hypothesized and actual changes in the real-world setting or the "client-system infrastructure" (Susman 1983), the action researcher gains both theoretical and practical knowledge about the phenomenon. Typically, action research is an iterative process that capitalizes on learning by both researchers and clients. Susman and Evered's (1978) canonical action research method formalizes the standards of this iterative and collaborative research process by describing it in terms of the following five phases:

- Diagnosing refers to the joint (researcher and practitioner) identification of situated problems and their underlying causes.
- Action planning is the process of specifying the actions that can improve the problem situation.
- Action taking refers to the implementation of the intervention specified in the action planning phase.
- Evaluating entails the joint assessment of the intervention by practitioners and researchers.
- Specifying learning denotes the ongoing process of documenting and summing up the learning outcomes of the action research cycle.

This paper reports findings from a longitudinal action research project on UCE in the Swedish road transport industry. The client-system infrastructure consisted of 4 stationary transport business systems vendors, 3 mobile systems vendors, 3 embedded systems vendors, 15 transport organizations, and researchers (see Figure 1). The project was directed by an action research team consisting of representatives from all involved parties. This "AR-team" was responsible for communicating the negotiations and planning of action to their respective organizations.

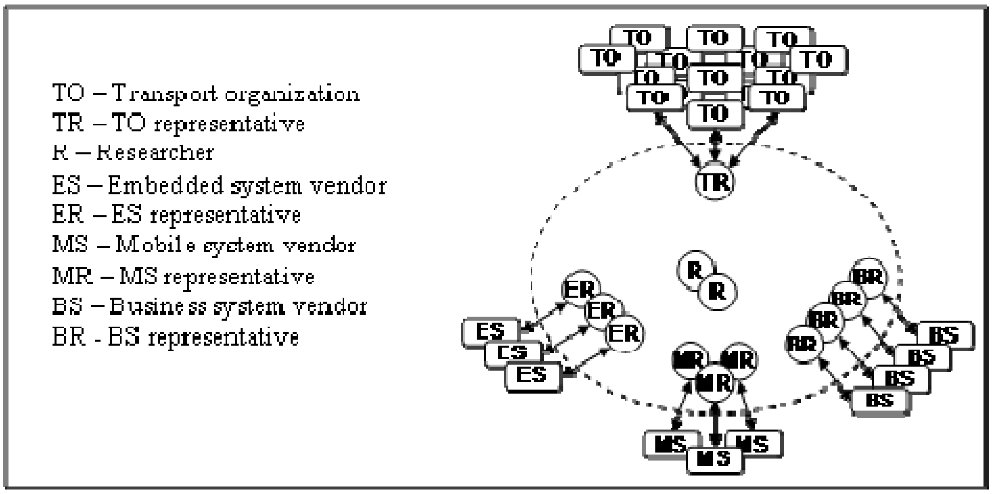

Figure 1: Client-system infrastructure

The diagnosing phase revealed that the transport organizations included in the study experienced difficulties in their attempts to utilize the combined strengths of stationary, mobile, and embedded computing. The problem with inflexible interpretation of context data was traced to the existence of a mobile-stationary (Andersson and Lindgren 2005; Lindgren et al. forthcoming). Guided by the initial diagnose, the action planned was to provide transport organizations with a viable ubiquitous computing environment, enabling them to manage their infrastructure in a way more suited to the relation between the context-aware properties of the technologies involved and their multifaceted use potential. Work was informed by extant general design requirements for context-aware ecosystems (Banavar et al. 2005). In order to rearrange the locus of context interpretation, it was assumed that a UCE must provide access to relevant context data in an open format suitable for reinterpretation and exploitability in a wide variety of uses.

In practical terms, the seams of the environment were to be manifested in an open XML-based mobile-stationary interface. Residing between mobile, embedded, and stationary components of a UCE, the interface would align the diverse actor groups and enhance the interpretational flexibility of mobile work processes from the user organizations' point of view. In addition, there were immediate practical incentives present for the participating vendors. As vendors of mobile and embedded systems generally managed most of the risk associated with problematic mobile-stationary integrations, a simplified procedure would carry substantial benefits by cutting development and maintenance costs. Indeed, incentives were also present for vendors of stationary business systems. Historically, business system vendors had with varying success deployed proprietary mobile-stationary interfaces embodying their representations of mobile work (Lindgren et al. forthcoming). However, they did not utilize data from embedded systems.

By simplifying access to such data, a standardized mobile-stationary interface would increase their opportunity for service innovation substantially.

Following the action planning phase, the research team developed a series of prototype interfaces serving as the basis for the continuous negotiation of the viability of the suggested approach. As the ambition of this project was to restructure the current practice of blending mobile, embedded, and stationary systems, success would depend on retaining commitment from the client system. Therefore, all design decisions and implications were to be negotiated within the AR-team continually providing ample opportunity to follow reactions among participating organizations. Whereas existing proprietary interfaces were utilized as a starting point, general design requirements for context-aware ecosystems (Banavar et al. 2005) guided the effort of producing a standardized mobile-stationary interface. In total, 6 iterations of prototyping were performed by the research team. Each prototype was informed by input and evaluative feedback from user representatives and vendors. The resulting prototype interface was then subject to another iteration of feedback and subsequent development. In order to track the reactions from the client system to the prototypes developed, these sessions were recorded and subsequently transcribed.

4.3 Data Sources and Analysis

The bulk of the empirical material comes from vendor and user organization interaction in project meetings (in total 9 meetings, each lasting between 4-6 hours). Supplemental material consists of:

- Interview data from 25 qualitative interviews (each lasting between 1-2 hours) with vendors and transport organizations (all interviews were recorded and subsequently transcribed).
- Conversations captured from a forum for developers.
- E-mail conversations among project group members.
- Transport organizations' feedback during prototype demonstrations.
- Research notes were taken throughout the project.

During the analysis, the collected data was examined for statements reflecting participants' reactions to important episodes in order to draw out specific implications for the relationship between the guiding working hypothesis and the divergent strategies of the participants (Walsham 1995). Notes taken throughout the study were compared to gain a richer understanding of the interactions utilizing insights gained at later stages.

5 FINDINGS

With the objective to counter difficulties surrounding usage of current computational solutions, the intervention was intended to develop a mobile-stationary interface embedding a flexible approach to interpretation of mobile work. By clarifying a division of concerns between mobile, embedded, and stationary vendors as well as user organizations, the anticipated outcome was a relocation of the locus of interpretation of context data utilized in this setting. However, the development process revealed a number of highly problematic issues pertaining to the guiding design requirements for context-aware ecosystems.

Given that a UCE must enable the exchange of context information across organizational entities, the initial step of the development process concerned open standardized models and context data formats relevant to the client system. Business system vendors had already deployed proprietary mobile-stationary interfaces embodying their representations of mobile work. While their interfaces were designed to facilitate integration of transport business systems and mobile systems, they did not utilize data from embedded systems. This profoundly influenced the current scope of systems integration. In keeping with this, the initial mobile-stationary interface prototypes were thought of as merely another interface. One of the business system representatives commented:

We've an XML-structure… a schema that is rather similar to this. We've put a lot of effort into it for a number of years. Our view of this is that it is sort of a de facto standard since there're so many customers running our XML-schema already. And this is another variant.

However, the UCE vision proved potent enough to retain the interest of the involved parties. As illustrated by this quote from a business system representative, they gradually came to a greater understanding of the potential of new innovation opportunities gained by standardized access to a published set of mobile context data:

Of course, some of these operational data types are important to associate with individual assignments in the transport business system. GPS coordinates are critical from a quality perspective. Odometer readings are interesting… perhaps for accounting purposes. For example, when you think you're not driving the distance you charge for. Quality control is important to see that the driver does not deviate.

Furthermore, in order to improve the capacity of user organizations to tailor interpretations of context, the initial prototype included a large number of essentially decontextualized low level vehicle data. As the following quote indicates, this was argued necessary by the user organizations:

The problem that we've today is that there are two actors who have good access to these systems. What we must strive for is to get more actors who have it."

Evident in this argument is the belief that open access to context data creates a foundation for innovative uses unconstrained by the currently restricted access. However, vendors of embedded technology became increasingly less enthusiastic about this development, fearing the loss of what they perceived as a proprietary repository of future in-house innovation and business opportunities:

All of the data that originates from the trucks is always stored in our systems. That's why we get into conflict here. We feel that this information is something that we can make into a unique service. That's something that we're not prepared to give away… we don't want to leave this business to someone else.

The ensuing negotiation highlighted the need for explicitly stated uses of context data without which the vendors of embedded systems would not allow access. In order to retain their commitment, an acceptable formula for the division of labor embodied within the interface had to be agreed upon. Indeed, several prototypes were designed to explore such compromises. A successful version ultimately rendered access to a subset of vehicle data syntactically coupled to processes of executing and evaluating assignments, leaving low-level data fully to the realm of the vendors of embedded systems. This version enabled access to the multiplicity of critical sources of context data viewed as necessary by the user organizations.

The capability of a UCE to dynamically discover and utilize new instances of context data sources was perceived a mixed blessing by the vendors of embedded systems as it would necessitate a shift of focus from complex integration procedures to swift deployment of their products. Indeed, the mobile-stationary interface was designed to simplify such processes. In spite of a principal agreement to the proposed course of action, there were indications that the simplified integration strived for was not necessarily beneficial from a vendor point of view. A representative of one of the vendors of embedded technology commented.

For a single actor in this mess there are benefits of becoming the best at managing these weird ways [of integration]. Somewhere along the line, we must all decide that this is how we would like to work.

Essentially, the fragmented market of embedded technologies made the adaptation of new context data sources a slow moving but nonetheless profitable market for vendors of embedded and mobile systems alike. However, at the same time, this approach also entailed an increasingly untenable maintenance burden as the number of unique integrations grew. Indeed, this development created the necessary incentive to proceed. As the initial strategy of providing access to low level data had to be modified in subsequent prototyping iterations, the final mobile-stationary interface included representations of context rather more specific than was originally intended. However, this in turn made future expansions of context data types more complicated than initially envisioned. In fact, new kinds of context data would have to be delivered in a standardized format requiring a continuous negotiation process. Viewing the embedded market as highly competitive and volatile, business system vendors feared that such processes would be too cumbersome, thus effectively hindering the successful diffusion of the interface:

Usually, the customer says that we would like to report this field. This means that we've to add a new field to the business system to display and report. In turn, this means changes to the standard, which requires management and maintenance and continuous development. I don't think that the customer will wait for half a year for that field to change, because by then they'll have lost their customer. You know, we're solving problems in real time. Given this, the standard should change dynamically. Otherwise we're cornered.

The ability to create representations of mobile work exploitable for multiple purposes was from the onset strongly advocated by user representatives. Even though the final prototype version only exhibited a limited capacity to increase the interpretational flexibility, transport organizations involved were happy with the result. The transport organization spokesperson asserted:

For us, the need is crystal clear. We see this as our chance to be proactive toward our customers, the transport buyers, to be able to sell additional services. Since a transport is a relatively simple service, we want to be able to sell more to our costumers… we see this as a crucial tool: the vehicle as a data producer that can generate data that is transferred directly into the business system without delay.

Thus, it was evident from their perspective that the locus of interpretation of viable usages of context data had indeed shifted, although not as radically as was initially intended.

6 DISCUSSION

As noted in the literature, the utility of existing computing environments including embedded sensor technology is generally hampered by parallel implementations of complementing sets of technologies (Banavar et al. 2005). Without a clear division of labor between suppliers of constituent technologies, the expressiveness of context data will be restricted to representations designed by vendors of the acquiring technology. However, at the same time, information infrastructures cannot be constructed from scratch. Indeed, the installed base of mobile, embedded, and stationary systems and user organizations has a significant influence on its future evolution (cf. Star and Ruhleder 1996). Clearly, practical attempts to erect ubiquitous computing environments require the negotiation and translation of interests of many different actors (Hanseth and Monteiro 1997). Utilizing this knowledge to actively intervene in a concrete problem situation exhibiting these characteristics, the research reported here adds to the current understanding of the design, implementation, and use of ubiquitous computing environments. More specifically, the paper contributes with an assessment of extant general design requirements for context-aware ecosystems (Banavar et al. 2005).

Concurrent with research on large-scale ubiquitous computing environments, the need to transfer context data between organizations was seen as highly important by user organizations. To make this feasible, an XML-based ontology of standardized concepts including context data was negotiated, utilizing pre-existing standards where applicable. The resulting interface was deemed to better cope with a distributed use than the previous proprietary solutions. However, the experiences with the interface point to important questions surrounding design requirements for context-aware ecosystems (Banavar et al. 2005).

First and foremost, access to context data provided by embedded technology proved to be a problematic issue. This study indicated that vendors of embedded technology were highly protective. This was especially true for the context data they generated. Indeed, their repositories of raw context data were seen as potential for in-house innovation and future business opportunities. It is likely that such commoditization of context data will continue to hamper the development of services in ubiquitous computing environments, thus playing out as an effective barrier to an envisioned open market context ecology (cf. Banavar et al. 2005). In this particular case, access had to be negotiated through the establishment of specific use contexts and associated services utilizing specific sets of context data. The negotiation of context resulted in a clear prescriptive way of creating exploitable representations specifying combinations of embedded, mobile, and stationary computing resources. To enable dynamic representations of context, a UCE must access a multiplicity of critical sources of context data from a potentially diverse set of providers. However, only a limited set of context data was utilized due to the protective strategies of vendors of embedded technology.

Analogous to the original problem situation, a priori interpretations were the result. However, progress was nonetheless evident as these were a product of a negotiation between the UCE constituents (mobile, embedded, and stationary systems vendors, and user organizations), as opposed to determined by the vendors of the data acquiring technology. This implies that the expressiveness of digital traces utilizing context data as perceived by end user organizations will be the result of a negotiation of viable usages, rather than built from readily available low level context data utilized by independent service level actors. Since a UCE must be able to dynamically discover and utilize new instances of context data sources, an associated strategy of “plug and play” proved to be a viable incentive for all involved parties.

To summarize, the requirements guiding the design process generated important general insights to research on ubiquitous computing environments. Indeed, the negotiation of context seems imperative to successful implementations of such environments. Open access to context data is of essential importance to create opportunities for flexible interpretations of mobile work for uses not anticipated in original representations. In spite of powerful incentives available, this essentially clashed with the business strategies of the actors supplying the acquiring embedded technology. Ultimately, this clash resulted in a negotiated compromise of limited access and a well-defined expansion of additional uses of context data between the involved actor groups.

Reflecting on the development process, the XML-based interface functioned as a boundary object (Star 1989; Star and Griesemer 1989) allowing for actors to exchange knowledge embedded in practice. Embodying the latest knowledge produced, the different versions of the interface enabled conversations by presenting representations of mobile work without enforcing a unique interpretation of context. This is especially necessary when heterogeneous actors engage in attempts to erect ubiquitous computing environments, because it is desirable that systems vendors and user organizations, while learning from each other, still maintain their own individual understanding. In this setting, the action research team played a critical role in translating, coordinating, and aligning different perspectives from multiple communities (cf. March et al.

2000). Clearly, tomorrow's ubiquitous computational solutions will depend heavily on complex boundary-spanning brokering processes.

A distinct learning outcome of this study is that the participating organizations have deepened their understanding of the complexity of accomplishing links between elements in assemblages comprising embedded, mobile, and stationary computing resources. In order to achieve sustained effects with regard to the design, implementation, and use of UCE, the organizations included in this study have formed the MSI Group (www.msigroup.se). Governed jointly by its member organizations, a mobile-stationary interface standard will be made available to the transport industry. In this way, the consortium is intended to become a critical collaboration platform for vertical IT standardization in the transport industry.

7 Conclusions

Real world attempts to assemble ubiquitous computing environments require alignment of heterogeneous socio-technical components (Lyytinen and Yoo 2002; Lindgren et al. forthcoming). Indeed, the negotiation and translation of interests of many different actors are essential (Hanseth and Monteiro 1997; Yoo et al. 2005). This paper has reported a study aimed at creating a well-defined and sustainable link between the installed base of mobile, embedded, and stationary technologies in the context of UCE.

Extant general design requirements for context-aware ecosystems proved useful for initiating change in the practical problem situation. In fact, they helped expand the scope of interpretation of combined mobile, embedded, and business computing resources through the negotiation of the representations of mobile work. Also, this study highlighted the complexity of governance related to ubiquitous computing environments (Lyytinen and Yoo 2002). In particular, embedded systems were seen not as objective deliverers of context data, but rather as a necessary vehicle for delivering ready made interpretations through end user services. These were based on the preconceptions of the utility of the technologies held by vendors. Thus, rather than committing themselves to the flexible interpretations often cited as an ideal in research (Banavar et al. 2005), a rather more limited increase of flexibility was the result of a finite and well-defined expansion of negotiated representations of mobile work.

Throughout the development process it was clear that there were incentives present for all involved parties. However, in this highly heterogeneous and competitive environment, the role of the researchers proved essential in providing guidance and support both as a neutral party and as suppliers of a theoretical foundation for the actions taken. As recently stated by Van de Ven (2005), there is a need to theorize innovation in large-scale complex socio-technical systems. In this context, a critical question concerns how vertical open interface development processes may be organized as to leverage component knowledge critical for architectural innovation. Complications presented here pertaining to the positioning of the locus of interpretation of context data in ubiquitous computing environments indicate that the divergent innovation strategies of heterogeneous organizations involved is a promising venue for further research.

8 REFERENCES

Abowd, G. D. Mynatt, E. D. “Charting Past, Present, and Future Research in Ubiquitous Computing”, *ACM Transactions on Computer-Human Interaction*, (7:1) 2000, 29-58.

Andersson, M. and Lindgren, R. “The Mobile-Stationary Divide in Ubiquitous Computing Environments: Lessons from the Transport Industry”, *Information Systems Management,* (22:4) 2005, 65-79.

Berg Insight. “Fleet Management and Wireless M2M”, *M2M Research Series 2006* (www.berginsight .com).

Banavar, G., Black, J., Cáceres, R., Ebling, M., Stern, E. and Kannry, J. “Deriving Long-Term Value from Context-Aware Computing”, *Information Systems Management,* (22:4) 2005, 32-42.

Baskerville, R. L. and Wood-Harper, A. T. “A Critical Perspective on Action Research as a Method for Information Systems Research”, Journal of Information Technology (11) 1996, 235-246.

Chalmers, M. and Galani, A. “Seamful Interweaving: Heterogeneity in the Design and Theory of Interactive Systems”, *ACM Designing Interactive Systems* (DIS2004), 2004, 347–356.

Dey, A. K. “Understanding and Using Context”, *Personal and Ubiquitous Computing* (5:1) 2001, 5-7.

Dey, A. K., Abowd, G. D. and Salber, D. “A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications”, *Human-Computer Interaction,* (16) 2001, 97-166.

Dourish, P. “What We Talk about When We Talk about Context”, *Personal Ubiquitous Computing*, (8) 2004, 19-30.

Fano, A. and Gershman, A. “The Future of Business Services in the Age of Ubiquitous Computing”, *Communication of the ACM,* (45:12) 2002, 83-87.

Godoe, H. “Innovation Regimes, R & D and Radical Innovations in Telecommunications”, *Research Policy*, (29) 2000, 1033-1046.

Grudin, J. “Group Dynamics and Ubiquitous Computing”, *Communications of the ACM*, (45:12) 2002, 74-78.

Hanseth, O. “Gateways—Just as Important as Standards: How the Internet Won the ‘Religious War’ over Standards in Scandinavia”, *Knowledge, Technology, & Policy*, (14:3) 2001, 71-89.

Hanseth, O. and Lundberg, N. “Designing Work Oriented Infrastructures”, *Computer Supported Cooperative Work*, (10) 2001, 347-372.

Hanseth, O. and Lyytinen, K. “Theorizing about the Design of Information Infrastructures: Design Kernel Theories and Principles”, *Sprouts: Working Papers on Information, Environments Systems and Organizations*, (12) 2004.

Hanseth, O. and Monteiro, E. “Inscribing Behaviour in Information Infrastructure Standards”, *Accounting, Management & Information Technology*, (7:4) 1997, 183-211.

Henfridsson, O. and Lindgren, R. “Multi-Contextuality in Ubiquitous Computing: Investigating the Car Case through Action Research”, *Information and Organization*, (15:2) 2005, 95-124.

Jessup, L. M. and Robey, D. “The Relevance of Social Issues in Ubiquitous Computing Environments”, *Communications of the ACM*, 45(12) 2002, 88-91.

Jonsson, K., Westergren, U. H. and Holmström, J. “Technologies for Value Creation: An Exploration of Ubiquitous Computing in Business Networks”, Accepted for publication in *Information Systems Journal*.

Lindgren, R., Andersson, M. and Henfridsson, O. “Multi-Contextuality in Boundary Spanning Practices”, Accepted for publication in *Information Systems Journal.*

Lyytinen, K. and Yoo, Y. “Research Commentary: The Next Wave of Nomadic Computing”, Information Systems Research, (13:4) 2002a, 377-388.

Lyytinen, K. and Yoo, Y. “Issues and Challenges in Ubiquitous Computing”, *Communications of the ACM*, (45:12) 2002b, 63-65.

March, S., Hevner, A., and Ram, S. “Research Commentary: An Agenda for Information Technology Research in Heterogeneous and Distributed Environments”, *Information Systems Research*, (11:4) 2000, 327-341.

Olsson, C. M. and Henfridsson, O. “Designing Context-Aware Interaction: An Action Research Study”, *in proceedings of IFIP WG 8.2,* Springer, Cleveland, Ohio, U.S.A., 2005, 233-248.

Roy, J. “Recent Trends in Logistics and the Need for Real-Time Decision Tools in the Trucking Industry”, *in Proceedings of the 34th Hawaii International Conference on System Sciences*, 2001.

Sambamurthy, V. and Zmud, R. W. “Research Commentary: The Organizing Logic for an Enterprise’s IT Activities in the Digital Era—A Prognosis of Practice and a Call for Research”, *Information Systems Research,* (11:2) 2000, 105-114.

Star, S. L. “The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving”, in *Readings in Distributed Artificial Intelligence*, M. Huhn and L. Gasser (Eds.), Morgan Kaufman, Menlo Park, CA, 1989, 37-54.

Star, S. L. and Griesemer, J. R. “Institutional Ecology, ‘Translations’ and Boundary Objects: Amateurs and Professionals in *Berkeley’s Museum of Vertebrate Zoology* 1907-39”, Social Studies of Science, (19) 1989, 387-420.

Star, S. L. and Ruhleder, K. “Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces”, *Information Systems Research*, (7:1) 1996, 111-134.

Susman, G. “Action Research: A Sociotechnical Perspective”, in *Beyond Method: Strategies for Social Research.* G. Morgan (ed.), Sage, Newbury Park, 1983, 95-113.

Susman, G. and Evered, R. (1978). “An Assessment of the Scientific Merits of Action Research”, *Administrative Science Quarterly*, (23) 1978, 582-603.

Walsham, G. “Interpretive Case Studies in IS Research: Nature and Method”, *European Journal of Information Systems*, (4) 1995, 74-81.

Van de Ven, A. “Running in Packs to Develop Knowledge-Intensive Technologies”, *MIS Quarterly*, (29:2) 2005, 365-378.

Weiser, M. “The Computer for the 21st Century”, *Scientific American*, (265:3) September 1991, 94-104.

Williams M. L. and Frolick, M. N. (2001). “The Evolution of EDI for Competitive Advantage: The FedEx Case”, *Information Systems Management*, spring 2001, 47-53.

Yoo, Y. and Lyytinen, K. “Social Impacts of Ubiquitous Computing: Exploring Critical Interactions between Mobility, Context and Technology - A Special Issue for Information and Organization”, *Information and Organization*, 15(2) 2005, 91-94.

Yoo, Y., Lyytinen, K. and Yang, H. “The Role of Standards in Innovation and Diffusion of Broadband Mobile Services: The Case of South Korea”, *Journal of Strategic Information Systems*, (14) 2005, 323-353.

Fifth Paper

5 Architectural Knowledge in Heterogeneous IT Innovation

Implications for Research and Strategy

Magnus Andersson, Rikard Lindgren, Ola Henfridsson

Abstract

Assembling heterogeneous and independent IT components into architectures is central to seamless service deployment in industry networks. Such assembling requires architectural knowledge. In this paper, we provide a theoretical perspective on how architectural knowledge may be developed to enable heterogeneous IT innovation in ubiquitous computing environment settings. This perspective is formalized as a research model that was developed and assessed over a five-year design-oriented action research project in the Swedish transport industry. We conclude with theoretical implications for IT innovation. In addition, we document the practical contribution to our client industry network and offer strategic implications for managers in other industry settings.

Keywords: Action research, architectural knowledge, component IT base, heterogeneity, IT innovation, ubiquitous computing

1 INTRODUCTION

After some years of progress in application-centered research (Abowd et al. 1997; Abowd et al. 2000; Weiser 1993), ubiquitous computing has now gained ground in the organizational world (Jonsson et al. in press; Lyytinen and Yoo 2002a; Lyytinen and Yoo 2002b; March et al. 2000; Roussos 2006a). Indeed, recent IS conferences (Sørensen et al. 2005) and special issues of premier IS journals (Topi 2005; Yoo and Lyytinen 2005) are indicative of the fact that ubiquitous computing has come of age. Behind the academic debate that surrounds ubiquitous computing is the growing evidence that organizations seek to assemble information environments that interconnect embedded, mobile, and stationary technologies as to innovate business propositions and increase customer value. As an illustration, managing and monitoring operations in the forest industry are becoming increasingly complex in response to driving forces such as cost reduction, new markets and products, and environmental demands. Critical business information needs to be seamlessly exchanged between distributed operations, central offices, and manufacturing facilities. To meet these requirements, forest companies extend the reach of their desktop decision-support tools by integrating them with sensor technologies of their forest machines. Through this technological innovation, defects (decay, knots, etc) may be dynamically considered in bucking and sawing decisions. Thus, the deployment of integrated technologies is critical for forest companies seeking to accelerate manufacturing, optimize raw materials utilization, and improve product quality.

Any ubiquitous computing environment (UCE) consists of an assemblage of heterogeneous base IT components (e.g., embedded, mobile, and stationary) being interconnected through communication technologies (e.g., cellular, PAN, and LAN) and application interfaces (e.g., XML-schemas). Lyytinen and Yoo (2002a) recognize that a UCE promises to function as a seamless infrastructure that solves a common set of needs for existing and future information services spanning organizational borders within an industry. Concurring with extant information infrastructure literature (Grindley 1995; Hanseth and Monteiro 1997; Star and Ruhleder 1996), no single UCE is developed from scratch. A UCE is rather modified gradually in response to multiple actors' (e.g., system vendors, user organizations, mobile network operators, and information service providers) concerns and actions.

Given the complexity following interaction between heterogeneous actors and technologies, a single organization seldom boasts the necessary knowledge and/or resources to innovate information services through combination of diverse base IT components. Indeed, innovating within the realm of UCE does not sit well with the received logic of IS innovation. New developments in IT seem to promote new forms of inter-organizational innovation (Boland et al. 2007; Yoo et al. 2005). As firms need to enhance their ability to collaborate and act in concert to develop knowledge-intensive technologies (van de Ven 2005), a pertinent question concerns the critical role of architectural knowledge and its nature during UCE innovation processes. Throughout this paper, we refer to architectural knowledge as knowledge developed and enacted in processes of aligning heterogeneous business and technical elements in an innovation process (cf. Henderson and Clark 1990).

Developing a theoretical model of heterogeneous IT innovation that integrates concepts from innovation theory (Henderson and Clark 1990; Lyytinen and Rose 2003; Yoo et al. 2005), this paper addresses two intertwined dimensions of architectural knowledge. First, UCE innovation involves component IT bases that are heterogeneous both in terms of technical capacity and their associated knowledge bases and markets. This means that orchestrating a UCE within an industry requires bridging of previously separated technologies and communities in processes of design and use. In this regard, the development of new architectural knowledge is an essential element in UCE innovation. Second, UCE innovation involves a period of intense struggle between a wide range of possible configurations before any one design can be considered dominant in an industry. In such times, a host of heterogeneous stakeholders attempt to define and impose on the industry an architecture that is based on their own specific perception of the capabilities of the component IT bases. However, firms involved in developing architectural knowledge, which eventually will define roles in an industry-wide UCE, are likely to experience that their participation in the innovation process is hampered by a lack of boundary-spanning know-how.

Looking at the extant IT innovation literature, it primarily focuses on post-adoption analysis of IT innovation (Grover et al. 1997; Lyytinen and Rose 2003; Swanson 1994). Thus, the received view is useful for describing and explaining innovation processes after the uptake of an innovation. However, except for Yoo et al.’s (2005) study of broadband mobile services in South Korea, there is a dearth of theoretical perspectives on the emergence of IT innovations capable of assisting firms involved in heterogeneous IT innovation. Targeting this gap in the literature, the paper presents a five-year design-oriented canonical action research study (Davison et al. 2004; Lindgren et al. 2004) within the setting of the Swedish transport industry. In collaboration with 10 system vendors (covering three IT bases: embedded, mobile, and stationary computing) and a group of road haulage firms, we addressed the following research question: *How can industries develop the architectural knowledge necessary for establishing an industry-wide UCE?*

Reflective of the dual goal of action research (AR) (McKay and Marshall 2001), our paper makes two important contributions. First, a theoretical outcome of this research is a perspective that explains how architectural knowledge can be developed through a collective achievement to establish an industry-wide UCE. Second, a practical outcome of this research is the creation of the “Mobile-Stationary Interface Group“ (MSI), which is a commercial consortium of vendors of embedded, mobile, and stationary transport systems, truck manufacturers, and user organizations governing an interface standard that is now available to the transport industry.

The remainder of the paper is structured as follows. In the next section, we review prior literature on IT innovation. Thereafter, we develop our research model for facilitating architectural knowledge development in the UCE context. This is followed by a method section that describes details about our AR project. Then, we present our two AR cycles. In the final sections, we develop implications for research and strategy.

2 Architectural Knowledge in Heterogeneous IT Innovation: A Research Model

2.1 IT Innovation

Broadly defined, organizational innovation refers to new applications of knowledge, methods, and technologies that leverage an organization’s competitiveness (see e.g., Becker et al. 1967; Daft 1978; Dewar et al. 1986; Rogers 1995; Sheremata 2004). While early work adopted a restrictive definition of innovation by limiting newness to the first user of an idea within an industry (Becker et al. 1967), later theoretical developments reflect a more inclusive view. The more inclusive view highlights the perception of newness among individuals, organizations, and communities as the basis for what counts as an innovation (Daft 1978; Lyytinen and Rose 2003). In this research, we take on board this type of understanding of newness.

Some ten years ago, Swanson (1994) recognized the role of IT in organizational innovation. Swanson developed a model of IS innovation including three distinct innovation types: process innovation related to the IS function, product innovation related to the IS function, and innovations related to core business technology. The model is widely accepted and has been empirically confirmed (Grover et al. 1997). However, it has been noted that it is primarily focused on innovation within a single organization (Boland et al. 2007). Moreover, the model does not incorporate the role of IT base changes. To this end, Lyytinen and Rose (2003) extend

Swanson's (1994) work as to understand organizational innovation occasioned by changes in the underlying IT base. Indeed, this extension was intended to explain changes following technological innovation residing outside the boundaries of an organization.

Lyytinen and Rose's (2003) notion of IT base includes three dimensions: base technology innovation, base development capability innovation, and base service capability innovation. First, base technology innovation concerns technological properties including issues such as "functionality, speed, reliability, architectural principles, and other features" (Lyytinen and Rose 2003, p. 562). Second, base development capability denotes the systems development changes triggered by the innovation. Third, base service capability refers to service changes triggered by the innovation. Analyzing these three dimensions, they show how innovation in the IT base is a necessary but not sufficient condition for system development and service innovation.

Lyytinen and Rose's (2003) analysis provides a promising direction for research that focuses on the role of innovations in the IT base for new applications of advanced technology in organizations. However, it does not accommodate the existence of heterogeneous IT bases, as is the case in UCE settings. Establishment of a UCE requires linkages between IT bases including embedded, mobile, and stationary computing capabilities to render system development and service innovations. Suggesting that development of such linkages is typically an emerging process of architectural knowledge creation, this paper recognizes the need of a process perspective for advancing the understanding of UCE innovation. Indeed, with the intention to stimulate the further development of their three-set model of IT innovation, Lyytinen and Rose (2003, pp. 581-582) underline this need in arguing that "IS scholars should engage themselves in more theoretical analyses of how IT innovations emerge and how they interact".

2.2 MULTI-ORGANIZATIONAL INNOVATION

Recent innovation literature has coined the notion of open innovation (Chesbrough 2006; Chesbrough et al. 2006) to frame the necessity of collaboration between innovating organizations. Whereas such innovation has become an important IS topic (Van de Ven 2005), it is vital to understand how actors with diverging strategic incentives and capabilities may cooperate to develop complex environments (Yoo et al. 2005). This shift in focus from the organization to the industry suggests the need for studies of complex interactions in infrastructural IT innovation processes spanning the boundaries of partaking organizations.

Yoo et al (2005) explore the development of the mobile infrastructure in South Korea through an actor-network theory lens. They conceptualize multi-organizational innovation processes as consisting of three distinct cycles: an innovation cycle affecting the innovation system, a diffusion cycle affecting the marketplace, and a regulatory cycle affecting the regulatory regime of any given complex socio-technical IT system innovation. The innovation cycle allows for new features to be "projected into the technological world and become established as candidates for future mobile services, enabling actors to relate to other actors and artifacts in new ways" (Yoo et al. 2005, p. 331). Typically, such innovation cycles are organized through generations of standards.

In this type of innovation environment, each organization contributes a specific set of capabilities that is dependent on the surrounding capabilities of others to generate meaning. Despite being dependant on others, organizations are still bound by the perceptions and strategies formed by experiences pertaining to their own positions in the value net that constitute the environment. Indeed, they are largely bound by their technological frames (Orlikowski and Gash 1994). As indicated by Lyytinen and Rose (2003) and confirmed by Yoo et al. (2005), actors in the base technology innovation system compete by innovating infrastructural technologies, which subsequently enable a different set of actors in the marketplace to innovate services building on the new base capabilities.

In view of our focus on how industries can develop the architectural knowledge necessary for establishing UCE, Yoo et al. (2005) offer a useful analysis of innovation processes that involve alignment of heterogeneous actors and associated technology components. However, they do not specifically look at the architectural knowledge required to assemble multiple independent IT bases for innovating systems development and services within an industry. As our analysis of UCE innovation in the transport industry will show, involvement of multiple independent IT bases (e.g., vendors of embedded, mobile, and stationary computing) both enable and constrain architectural knowledge development.

2.3 ARCHITECTURAL KNOWLEDGE

Henderson and Clark's (1990) theory of architectural innovation suggests innovation to be the result of changes in the composition of already existing components. This theory was developed as to explain innovation patterns involving novel products that combine existing ideas or technologies in a useful way (cf. Hage 1980). Architectural innovation refers to a process of assembling a product's components in ways that radically improves customer value and satisfaction. Whereas the product architecture is new, the components and their knowledge foundation remain unchanged. Thus, in architectural innovation theory, a product is understood in terms of a set of components (Henderson and Clark 1990). First, a product consists of a set of components, each implementing a distinct portion of the product and performing a well-defined function. The implementation of this well-defined function embodies a core design concept. While the functional basis of this definition reflects the idea that a specific component may rely on alternative core design concepts, a dominant core design concept builds on a distinguishable body of knowledge, i.e., component knowledge. Typically, such knowledge has been acquired, applied, and refined over a long period of time**.**

In UCE settings, component knowledge (IT base knowledge) resides with the particular IT base as well as the industry relationships and markets developed around this base. For example, embedded computing is an IT base with particular focus on the mobile side of transport organizations, that is, the set of technologies and corresponding knowledge bases surrounding the vehicles. Second, a product relies on an idea of the integration and linkages between each of the components. As Henderson and Clark (1990) suggest, this idea draws on a specific kind of knowledge, i.e., architectural knowledge. For the purposes of this paper, we define architectural knowledge as knowledge being developed and enacted in a collective achievement to align independent heterogeneous actors and technologies in an innovation process.

Henderson and Clark's (1990) model assumes an evolutionary perspective on innovation. In the early stages of an innovation's existence, there exists a lot of experimentation and improvisation. In a struggle for dominance, multiple incarnations of architectural innovation initially exist side by side. Over time, gradually stabilizing architectures are reflected in the internal communication channels and associated filters running through individual organizations (cf. Daft and Weick 1984). As a result of such adaptation, an organization is prepared to competitively tackle evolutionary developments within the current architectural scope. In fact, the consolidation of architectural knowledge serves to fine tune the organization's internal innovation activities. However, the crossing of organizational boundaries is likely to add to the costs of information transfer. Therefore, an effective way to improve the transfer of sticky information is that firms seek to align their organizational boundaries (and their specializations) with the partitioning dictated by the types of innovation-related problem-solving tasks that they perceive as most important (von Hippel 1998). To some degree organizational layouts may be viewed as mimicking the arrangement of components forming the complete architecture of an actual finished product.

Whereas firm-based product development is the typical avenue for studies of architectural innovation, recent work has focused on complex infrastructural and multi-organizational settings (Soh and Roberts 2003). The UCE setting is even more complex because the IT bases often are finished products or systems in their own right rather than mere components. As such, independent IT bases and associated vendors and markets already exist. However, their actual interlinking into a UCE necessitates architectural knowledge development through collective achievement. Such boundary-spanning knowledge development may be highly problematic as the individual firm's learning with respect to new outside information is largely a function of the firms prior related knowledge (Cohen and Levinthal 1990). Cognitive filters associated with one IT base become barriers in a UCE context in that alignment of technologies requires component knowledge of multiple IT bases. With the objective to overcome these barriers, novel communication channels and filters must be developed, thus enabling the formation of architectural knowledge spanning multiple (component) IT bases.

While Henderson and Clark's (1990) original formulation of architectural innovation is effective for theorizing activities of individual innovating firms, architectural knowledge in contemporary IT innovation is characterized by its boundary-spanning quality supporting inter-firm mobility of information for improved business operations (Van de Ven 2005). In hybrid industries composed of increasingly heterogeneous actors, processes of development and management of architectural knowledge are indeed difficult to master. Encompassing radically diverse computing capabilities, the case of UCE is a representative example. The specific problem is that the innovation potential of the environment is essentially distributed across competitors as well as IT bases, each having an independent market. As a consequence, the complexity of orchestrating complementary resources (Teece 1986) increases, thus further complicating the way in which heterogeneous actors may collectively explore and exploit architectural knowledge. While the development of communication channels and filters across firms is a key ingredient in UCE innovation, instantiations such as standards may play a complementary role when it comes to articulating architectural knowledge and explaining its nature. Although Yoo et al. (2005) do not specifically address the issue of how architectural knowledge development affects industry attempts to assemble multiple independent IT bases, their study provides evidence for the hypothesis that standards help heterogeneous development collectives to innovate by aligning and coordinating actions of different actors. Indeed, evidence from standard-making in other industries confirms the centrality of mediating standards in endeavors to weave heterogeneous technologies into everyday work practices (e.g., Markus et al. 2006).

2.4 A RESEARCH MODEL

Informed by the literature reviewed above, we now formalize the discussion into a research model of architectural knowledge in heterogeneous IT innovation (see Figure 1). Each component represents an independent market built on a specific IT base (i.e, component IT base). Over time, firms operating in a particular market have developed a distinguishable body of knowledge that has been acquired, applied, and refined over time. We refer to this stock of knowledge as component knowledge.

In heterogeneous IT innovation, two or more components are interwoven as a result of a collective activity of firms operating in different markets. In this regard, they create an architecture that links the independent components in ways that serve the interests of the clients of an industry. In order to do this, architectural knowledge, (i.e., knowledge being developed and enacted in a collective achievement to align independent heterogeneous actors and technologies in an innovation process) needs to be developed. In this research, we propose that such architectural knowledge relies on a) the development of communication channels and filters between firms, and b) the instantiation of architectural knowledge through IT bases boundary-spanning standards.

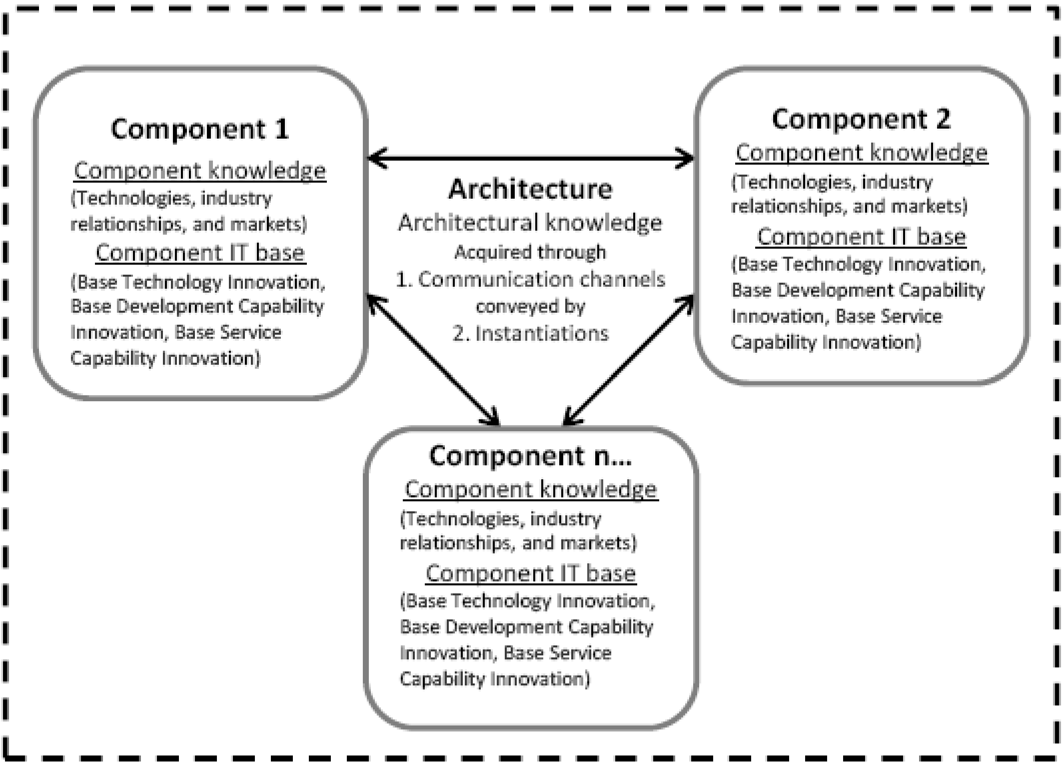

Figure 1. A research model of architectural knowledge in heterogeneous IT innovation

Given this theoretical perspective, we set out to explore the emergence of architectural knowledge in the Swedish transport industry. We embarked on a design-oriented canonical AR study (Davison et al. 2004; Lindgren et al. 2004) with key actors to explore the role of architectural knowledge and its nature during UCE innovation processes.

3 RESEARCH METHOD

3.1 RESEARCH SETTING

Road transport is critical for the European economy (Berg Insight 2006). Each day, EU-based transport organizations deal with 15 million courier, express, and parcel shipments, carrying a total of approximately 50 million tones of goods. Of all goods moved within EU, commercial vehicles transport 44 percent. With regard to EU inland freight transport, trucks move 74 percent. In 2002, the total volume of road transports undertaken by EU registered haulers was 1,347 billion tones-kilometers. While national transport accounted for the vast majority of the total road transport volume, international transport made up some 20 percent.

The empirical setting of this paper is the Swedish road transport industry. Despite significant growth, this industry undergoes changes occasioned by the European Union’s open market, where foreign transport firms have increased their market share considerably. Swedish transport organizations are therefore faced with increasing pressures to leverage their business propositions and operations at different points in the supply chain. To this end, the operations of transport organizations involve an increased utilization of different information technologies.

Component IT base	***Functionality***	***End-users***
Stationary IT base: • Desktop systems • E-business solutions • Office automation technology	This type of IT support is aimed at improving transport management efficiency: • Event-triggered alerts and geo-fencing • Geo-positioning • Navigation and route optimization • Order management • Route optimization software • Vehicle, cargo, and goods monitoring and tracking	• Managers • Dispatchers

Mobile IT base: • Nomadic devices integrated with vehicle electronics in cockpit • Vehicle-mounted communication terminals	This type of IT support is aimed at improving the efficiency of mobile workers: • Communication between stationary personnel and mobile workers • Information about mobile workers' positions • Text messaging	• Drivers
Embedded IT base: • Active ignition sensing software • Barcode scanners • CAN-bus • Electronic trip recording software • GPS receiver • RFID technology	This class of IT support is aimed at improving vehicle utilization and driver productivity: • Breaking and shifting behavior analysis • Driving and stopping times tracking • Driver working time analysis • Fuel consumption and trip distances monitoring • Maintenance planning • Navigation software	• Managers • Drivers • Dispatchers

Table 1: Component IT bases in transport industry

Table 1 depicts three market segments of IT support in transportation. Manifesting different IT bases (Lyytinen and Rose 2003), there exist a stationary, mobile, and embedded market, each addressing different aspects of transport management and operations. The stationary segment relies on desktop systems, servers, and e-business solutions as well as more traditional office automation, and this IT base responds to the needs of transport management with managers and dispatchers as end-users. The mobile IT base deals with mobile computing platforms facilitating drivers' day-to-day work and communication. Finally, the embedded IT base deals with technologies embedded in vehicles, such as vehicle networks, RFID, and sensor technology, for improving the utilization of the fleet of vehicles and driver productivity.

Generally, the ultimate clients of our research, Swedish transport organizations find the fragmentation between IT bases problematic, as the system vendors on each market only offer partial solutions to their need of IT support. Seeking comprehensive solutions that, e.g., facilitate data interchange between systems, transport organizations have to build new, architectural knowledge for inter-linking these partial solutions. Entering this study, such architectural knowledge was difficult to build in collaboration with existing system vendors, as vendors of components strived to dominate the entire market scene and integrations with other components were done on a case-to-case basis. Such strategies emanated from the specifics of the IT base in question, tilting the focus of the resulting assemblage towards that specific area of core competence. This was especially so in the case of stationary vendors.

3.2 Research design

Given the problem situation characterized by a lack of architectural knowledge among transport organizations and system vendors, we initiated an AR study that would explore how industries can develop the knowledge necessary for establishing an industry-wide UCE. The study spanned over a 5-year period. Conducted between August 2002 and September 2007, the “Value-Creating IT for Road Haulage Firms” project[6] was a collaborative effort between the Viktoria Institute and a large transport industry network. The industry network consisted of ten system vendors (Hogia, IBS, NL Partner/Locus Scandinavia, MobiOne, Mobistics, Scania, Transics, Transware, Vehco, and Volvo Trucks), a number of road haulage firms (AA, SÅAB), and a consultative organization owned by 15 Swedish transport organizations (TRB).

Representing these main system vendors and a sizeable part of the combined fleets in the Swedish transport industry, the industry network brought considerable transport system development experience covering all three IT bases (stationary, mobile, and embedded) to the project. The action researchers brought previous experience of designed-oriented AR and ubiquitous computing in telematics (see e.g., Henfridsson and Lindgren 2005; Lindgren et al 2004), as well as knowledge about general IT innovation theories. Using Avison et al's (2001) classification of authority and control, the control structure of the AR project can be classified as staged. The project was initiated by the researchers, but once the Client-Researcher Agreement (Davison et al 2004) was signed the authority of the project was assigned to a team consisting of practitioners and researchers. The second author of this paper acted as the project manager over the five-year study.

As an interventionist method, AR allows the researcher to test a working hypothesis about the phenomenon of interest by implementing and assessing change in a real-world setting. Of the many AR approaches available to IS researchers (Baskerville and Wood-Harper 1998), canonical AR (Davison et al. 2004; Susman and Evered 1978) was selected because of its cyclical process model, rigorous structure, collaborative researcher involvement, and primary goals of

[6] The project was funded by VINNOVA and the participating organizations. VINNOVA is the Swedish Agency for Innovation Systems, which integrates research and development in technology, transport and working life. VINNOVA's mission is to promote sustainable growth by financing R&D and developing effective innovation systems. For more information, go to http://www.vinnova.se/.

organizational development and scientific knowledge (Baskerville and Wood-Harper 1998). Given that a perspective on architectural knowledge in IT innovation would require repeated cycles of inquiry in which the emerging theory was refined throughout the process, the cyclical nature of canonical AR was considered especially useful. In addition, as to secure a solid and sound research process in collaboration with a vast industry network, the rigorous structure of canonical AR was deemed valuable in developing contributions to both research and practice.

3.3 Research process

Canonical AR formalizes the standards of the research process by describing it in terms of the five phases of diagnosing, action planning, action taking, evaluating, and specifying learning (Susman and Evered 1978). Our research consisted of two full AR cycles. The problem of fragmented solutions, or the mobile-stationary divide (Andersson and Lindgren 2005), was addressed in the first AR cycle. In particular, our diagnosis directed the inquiry on how to develop architectural knowledge among vendors of office, mobile, and embedded solutions for testing the working hypothesis that the development of communication channels and filters between firms, belonging to different component IT bases, is critical for developing architectural knowledge in UCE settings. Concurring with canonical AR (Susman and Evered 1978), this hypothesis guided the subsequent phases of the AR cycle. In the action planning and taking phases, we established communication channels by setting up a formal network between representatives of each IT base and formulating a joint project description. The action taken was then evaluated through user site investigations in seven integration projects within the industry network.

On the basis of the understanding gained in the first AR cycle, we re-formulated the working hypothesis that would guide the remainder of our research. We specified a direction of the project that would test the working hypothesis that instantiating architectural knowledge through a standardized interface is necessary to complement the establishment of communication channels in order to leverage heterogeneous IT innovation. Following this hypothesis, the AR team planned and initiated iterative development and evaluation of MSI, a vertical standard for the Swedish transport industry. MSI was tested by evaluating the extent to which vendors adopted the standard in their applications and the interest shown by road haulage firms.

3.4 DATA SOURCES AND ANALYSIS

Concurring with the typical AR project, our data collection involved numerous data sources including project and workshop sessions, public industry presentations, work meetings, document reviews, technology reviews, and semi-structured interviews. Table 2 provides an overview of these sources.

Data Source	***AR cycle #1***	***AR cycle #2***
Project meetings	4	16
Work meetings	2	36
Interviews	59	21
Workshops	2	3
Strategy documents	Documents describing organizational strategies	
Technical documents	Review of product documentation	Proprietary interface documentation MSI prototype interface specifications
Observations	30 hours	-

Table 2: Overview of data sources

The three main sources of data are project meetings, work meetings, and interviews. In total, 20 project meetings were held in the five-year project. Typically chaired by the second author of this paper, the meetings were central to manage the project and mobilize support for the research agenda. The recorded and transcribed material from these meetings was important sources for collecting data on the actions taken in the project. Second, numerous work-meetings were held with client organizations. These were typically led by the first author of this paper and concerned the technical development of prototypes. Since many views relevant to the development of architectural knowledge were revealed at these occasions, most of the meetings were tape-recorded and transcribed for later retrieval during the data analysis. Finally, 80 formal interviews were performed, recorded, and transcribed in the diagnosing and evaluating phases of the AR cycles. Respondents included technology vendors, developers, drivers, dispatchers, and user organization managers. Most interviews lasted more than 90 minutes and covered different themes relevant IT development and use in the transport setting. In addition to these main sources, we had access to a large quantity of data pertaining to strategy and technical documents, user site observation, informal conversation, e-mail, and dedicated forum conversation.

4 ACTION RESEARCH CYCLE #1

4.1 DIAGNOSING

The project started when Vehco, a system vendor, contacted Viktoria Institute for discussing mutual interests in IT support in the transport industry. As a relatively new start-up, Vehco desired to leverage what they considered to be their core competence – customer understanding – by initiating a research project with an institute recognized for its studies of user-oriented IT studies. In view of the recent formation of the Telematics Group, this idea was embraced by Viktoria researchers. Vehco and Viktoria decided to initiate a diagnosis of the current state of IT support among transport organizations.

To get an initial industry understanding, we visited the annual trade fair and held numerous informal meetings with technology vendors offering different IT solutions. An early observation was that vendors were surprisingly technology-focused. As an illustration, a transport business manager with several years of experience from implementing transport technologies asserted:

They are continuously trying to create needs… convincing people to invest in this stuff. […] For example, in view of environmental concerns, they will try to equip the truck with a lot of things. And they will force us to use it. I have no idea how this will turn out… I don't think that they should continue to just add more and more technology. We will reach a point where we are no longer interested in buying their trucks.

Rather than portraying their offerings in terms of customer value, vendors tended to highlight the technological excellence relative to other vendors. As a result of the problematic situation, transport organizations tried to develop and implement their own solutions. A transport and logistics manager at Volvo commented:

Contractors of haulers and large road haulage firms develop their own tailor made solutions, thus acting as system integrators. They utilize development resources and hardware in an ad hoc fashion in their attempts to accomplish some form of proprietary total solution. Typically, in five years time they have decided to throw the rubbish.

Given this situation, we decided to review the different systems available. A key here was to identify the core competence of each group of vendors. However, this turned out to be a difficult task because of the heterogeneity of technologies. Basically, there were three camps. We started to refer to these as the stationary, mobile, and embedded, highlighting the different IT bases and trajectories that vendor solutions could be traced to.

Of course, the heterogeneity of available IT support and associated actors was also perceived by customers struggling to make this complex environment useful. In our discussions with the Swedish Road Haulage Association, the president highlighted that heterogeneity of technologies and vendors was problematic for his members. Given the relatively low IT competence among road haulage firms, the technological jargon of vendors did not facilitate fit between systems offered and problems perceived.

Encouraged by the Road Haulage Association and Vehco, we initiated an interview study of road haulage firms' experiences of IT use. Over this study, we soon realized that the heterogeneity of IT bases was not only a matter of jargon but a real-world problem manifested in vendors' inability to understand the whole problem situation when implementing their solutions. In short, user organizations were not satisfied with the competence of a single vendor to cater for all of these bases. One manager at a transport organization commented:

Well, it's positioning, route planning, vehicle data collection, and so on. There are plenty of vendors to choose from to get vehicle fuel consumption data and all sorts of things. But they don't have a comprehensive approach.

The lack of a comprehensive approach was echoed in many other testimonies of transport organizations. Rationalizing why no such approach was given, the manager continued by exemplifying his experience with a vendor of embedded technology:

They have been confined to their own world. I mean, if we are to have something in the truck, we must be able to adapt it to what we have in the office, our transport management system. But they have not been willing to do that. They argue that we should use their stuff both in the trucks and in the office, and that has not worked.

In analyzing the situation at the investigated transport organizations, we noted that they considered most vendors being confined within their own technological paradigm. Seeking a comprehensive solution that bind different IT components together, the industry at this stage was characterized by fragmentation. As a manager at one of the transport organizations noted:

This is a problem because I feel that we are waiting for the ultimate system that binds everything together so that you don't have to deal with 14 different systems. Positioning and dynamic vehicle data together with maintenance systems and the transport management system and everything. But that's just a wishful dream. It will never be like that I suppose.

At this stage of the diagnosing phase, we decided to feed back our lessons learned from the interview study to technology vendors and transport organizations at a combined seminar and workshop. We were surprised to learn that this was basically the first time that these actors met to discuss industry concerns in a collaborative session. While we assumed that the fragmentation perceived by their clients would stimulate collaboration initiatives, we concluded the workshops with an understanding that better communication channels were needed to facilitate the comprehensive architectures needed in practice. This conclusion was not least based on the fact that little communication beyond courtesy phrases was triggered at this occasion.

Summarizing the diagnosing phase, we identified an underlying reason to transport organizations' perceived fragmentation: knowledge sharing between heterogeneous technology vendors was non-existent. Given this empirical problem situation and our review of innovation literature, we specified the following working hypothesis: *the development of communication channels and filters between firms, belonging to different component IT bases, is critical for developing architectural knowledge in UCE settings.*

4.2 Action planning and taking

Following our working hypothesis, our plan for the remainder of the action research was to establish communication channels that we hypothesized was necessary to create architectural knowledge within the industry network. Our hope was to establish links over the boundaries of predominantly stationary, mobile, or embedded technology oriented organizations.

To this end, we established a formal network of system vendors and road-haulage firms to build a basis for developing architectural knowledge. The founding members of this network were: Viktoria Institute, Hogia, NL Partner[7], Scania, Vehco, and Volvo. The network was intended to create communication channels between previously disconnected organizations operating within various component IT-bases. As to secure commitment and specifying roles and responsibilities, the community was formalized in a researcher-client agreement (Davison et al. 2004). A

[7] NL Partner was acquired by Locus Scandinavia in late 2005.

governmental funding agency (VINNOVA) was aligned to the community as to generate resources for what eventually opted to sustainable network effects of the AR effort. After assessment of the network's proposal, funding was approved for rendering "value-creating IT for road-haulage firms".

Following the formation of the network, five additional system vendors (IBS, MobiOne, Mobistics, Transics, and Transware) were aligned to the network. This expanded network represented the main-part of vendors operating in the Swedish transport industry at the time.

4.3 EVALUATION AND SPECIFYING LEARNING

With the industry network in place, the next step was to explore our working hypothesis that communication channels and filters are necessary to develop architectural knowledge. To this end, the AR team, consisting of researchers and representatives from the partaking organizations, decided on an evaluation strategy. This strategy was to tap knowledge from ongoing integration projects to a) identify and specify important dimensions of architectural knowledge and b) identify traces of architectural knowledge developed on the inter-firm level. It was decided that 7 integration cases would be basis for feeding back experiences on these aspects. In practice, members of the industry network offered researchers access to their most advanced cases of technology integration.

Throughout the evaluation phase, an understanding of dimensions of architectural knowledge emerged. First, a critical issue was whether any single technology vendor would have the capacity to cater for a complete architecture including heterogeneous technologies. Even though there were actors who took on this single vendor role to meet transport organizations' expectations, most vendors studied realized their inability to handle IT components outside their core competence. The CEO of Vehco (vendor of embedded technology) commented on this low awareness of technology capability among vendors:

Vendors of stationary transport management systems who have tried to solve the mobile part have typically failed. […] However, there are examples of vendors who have decided to focus their business. For example, one of our competitors has recently dropped the idea of developing a stationary transport system. In fact, no single actor has the capacity to cater for a total solution. And if we have had a vendor capable of solving the puzzle integration should not be an issue. However, the multitude of technologies makes it too complex… One of our Swedish truck *manufacturers has reached for the total solution to the needs of transport business… given that they have failed it is fair to say the case is closed.*

Second, in our evaluation, we also noted that there existed a low sensitivity to user contexts in general and to such contexts relating to other components in particular. In one of the cases studied, a vendor of mobile technology had implemented a system for optimizing mobile resource allocation at a transport organization. Utilizing GPS technology, transport dispatchers were supposed to continuously pinpoint the location of individual trucks on a dynamically updated map representation of the aggregated mobile context. The CEO pointed out that dispatchers would not have to rely on extensive verbal negotiations with drivers to transfer information from the mobile context to their stationary, thus speeding up the allocation process. However, it soon turned out that there was more to the mobile context than positioning. With the new system, drivers had the option to decline a given assignment from the dispatcher. According to dispatchers, this option diminishes the perceived utility of a sensor fed representation of the mobile work context:

We question their option to decline. Now you have to call them all the time and ask: 'Why did you decline? What are you going to drive instead? What have you got that we do not know about?' And then we have lost the whole point.

In essence, the introduction of the mobile system illuminated a complex negotiation process between drivers and dispatchers. As the perceived efficiency gains of the system were endangered, dispatchers wanted the systems representation to enforce their organizing logic and deprive the mobile actors the opportunity to engage in communication and collective creation of cross contextual knowing. The emphasis on the stationary representation was also evident with the vendor of the transport planning system:

What we are targeting [with our system] is actually all that is going on in the office. We have little control of what goes on in the vehicles. […] Of course, they [the customers] ask us what we find appropriate for them to have in the vehicles, but we do not really care.

Even though the mobile system acquiring the context data was integrated with the stationary system, the representations were in effect still separated. The utilization of embedded technology was essentially subject to the prior understanding of work practice embedded into the design of the stationary system. Essentially, the sensor data was meant to replace much of the ongoing negotiation between dispatchers and drivers. As highlighted in the case, this clashed with the current work practice of dispatchers. This is an example of a low level of use context sensitivity among technology vendors.

A third subset of architectural knowledge that we identified was what we referred to as business model understanding. As the cases indicated, there were situations in which different views on underlying business models caused problems. Discussing the utilization of data from embedded technology, a transport manger of one the case organizations commented:

It is a matter of taste what you would like to have or what you should have... simply whether you wish to get access to all this information. Should you really pay for the trip analysis feature if it renders an extra cost? In case it would be a significant difference, I would have dismissed it. To me driving time, navigation, and track and trace are the primary features. Well, I have indeed told them that CAN bus data is outside our primary scope... I guess that was somewhat stupid... I don't know actually, it seems as if it is part of their standard package... and it is not interfering in any way. And I don't think it will cost less or something like that if we exclude it.

It was clear that actors (both vendors of technology and transport organizations) were uncertain how to develop a viable business models for data produced by embedded technology. It was particularly so in situations where truck manufacturers were involved in integration of heterogeneous technologies. A telematics manager at Volvo Trucks put in this way:

We are actually investing quite a lot in analyzing what we have… honestly; there is a lot of rubbish. The trick is really to capture the data that we can refine and sell to our customers. We can generate and store tons of data… but, again, in terms of internal usefulness, there is plenty of data that is interesting for us but not for the customer.

At this stage, three dimensions of architectural knowledge in heterogeneous IT innovation had been identified: technology capability awareness, user context sensitivity, and business model understanding. This was important as to create a common understanding of architectural knowledge in the industry network. However, it was clear that we saw few traces of architectural knowledge in the cases studied. Experiences from the integration cases highlighted the inability of actors to collaborate as a contributing factor. Indeed, it seemed that successful integration of heterogeneous technologies required knowledge sharing and learning among the involved actors in actual projects. A manager at one of the case transport organizations analyzed the boundary-spanning ingredient of integration projects:

Primarily, we have discussed with Vehco. But, what transport management systems are available today? I guess that the answer is SA-Data and Hogia. My experience is that they act differently; SA-Data is doing it in their way, and the same can be said about both Hogia and Vehco. The question is whether they can coordinate their actions. If they would collaborate they may decide that Vehco is responsible for that part [of the solution] […]. Simply, for this to work, it is not just about implementing Vehco's application. That is not the way it works.

The AR team partially traced this inability to the reliance of proprietary interfaces among individual vendors. Such proprietary interfaces were published by stationary vendors to be utilized by their mobile and embedded counterparts for assembling the customer organizations computing environment as a whole. Mobile and embedded vendors had to comply with these interfaces to be able to enter the market. While these interfaces specified the capabilities of the stationary systems, however, there were little or no dedicated support for mobile and, particularly, embedded technology present. Indeed, these artifacts helped perpetuate the mobile stationary divide in that effectively separated relevant actors. A manager of one of the vendors of stationary technology commented:

Yes, we have developed our own XML interface. Honestly, this interface clearly marks the boundaries of our scope. And then it is up to our customers to decide whether it is good or bad. We don't know anything about the mobile context (the truck). And even if we knew something we wouldn't say anything because we don't know much about the vendors out there.

The potential of the computing environment became dependant on the technological frames and market strategies of vendors of stationary technology alone. Though the problems within the industry network persisted, the main assumption was still valid. It was evident that the process of improving architectural knowledge needed active input from all identified parties, vendors from all relevant IT bases as well as user organizations. Unfortunately, the utilization of proprietary interfaces negatively affected the way actors interacted in integration projects.

In view of the problems created by proprietary interfaces, there were actors who called for the development of open standards, facilitating the interaction between heterogeneous actors and technologies. A telematics manager at Volvo Trucks put in this way:

In the current situation, we are actually discussing the need of a standard with different actors. The existence of a multitude of special protocols is a disadvantage to us. We would like to have an industry standard that allows us to integrate Dynafleet with ERP packages and different stationary transport management applications.

In the same vein, there were vendors of stationary transport systems who identified that a standardized industry interface would help resolve many of the problems surrounding integration of embedded, mobile, and stationary computing. However, as was articulated by the manager of Locus Scandinavia, most of them raised concerns about who would take responsibility for such an initiative:

There are way too few standards available in the transport business. For us, a standard for [system] communication between the office and the truck is the most important. Unfortunately, it seems that no one is ready to take the lead. While the Swedish Association of Road Haulage Companies would be a natural choice, they don't bother. The Faros Mobile Standard could have been valuable, but as far as I know it is designed for contractors of haulers. Thus, it is not adapted to business processes of smaller transport firms.

In view of the fact that the AR project has aligned the majority of the technology vendors available, there were actors who suggested that the AR project provided a suitable arena for the development of an industry standard. The CEO of Vehco commented:

It would be really valuable if you would contribute to the development of a standard interface in the transport industry. A standard would make life easier for many actors. […] A standard is really what this industry needs; something that the actors can gather around.

Alongside the identification of subsets of architectural knowledge, the AR team learned that the improving the boundary-spanning competence of vendors was critical for resolving the integration problems that transport organizations experienced. It was also clear that the existence of proprietary interfaces obstructed value-creating interactions among vendors. Following our research model, the AR team decided to organize AR cycle 2 so that the subsets of architectural knowledge identified would be instantiated in an industry standard. The idea was that the development of an industry standard would offer a situation in which actors would get the opportunity to improve their boundary-spanning competence.

5 ACTION RESEARCH CYCLE #2

5.1 DIAGNOSING

Based on the evaluation of the outcome of the first AR cycle, we agreed to initiate a second cycle. Given the importance of boundary-spanning competence and proprietary application interfaces, a diagnosing phase consisted of a comparative analysis of vendors' proprietary software interfaces. This analysis was intended to further clarify how proprietary interfaces affect the possibility of a common architecture. For instance, the analysis showed that application interfaces from stationary vendors were lacking descriptions of technological capabilities outside the stationary context such as fuel consumption metrics or working time data. In practical terms, this could explain why such capabilities did not become an integral part of current UCE innovation. In view of this analysis, and based on the insufficient effect of the first AR cycle, we adopted the following working hypothesis for the second AR cycle: *The instantiation of architectural knowledge through IT bases spanning standards is a necessary complement to boundary-spanning communication channels and filters in UCE innovation.*

5.2 ACTION PLANNING AND TAKING

Based on the diagnosing phase, we developed a plan for designing a standardized "mobile stationary interface" (MSI) utilizing component knowledge from all actors in the industry network. In this regard, MSI was intended as an instantiation of architectural knowledge across the earlier specified dimensions of such knowledge: technology capability awareness, user context sensitivity, and business model understanding. The practical objective was that MSI should promote innovation by creating an inclusive coupling of the stationary, embedded, and mobile components of the overall UCE architecture. Apart of such coupling, it was imperative to recruit a user organization with first-hand experience of integration projects to the industry network. To this end, the AR team identified and recruited TRB. TRB is a consultative organization jointly owned by 16 transport organizations, which organize a sizeable part of the Swedish fleet.

To maximize the diffusion potential of MSI, we decided to ground MSI development on technological solutions known to the industry network. Extensible markup language (XML) was used by some vendors to construct their application interfaces and more were in the process of adopting it. XML was therefore chosen for MSI development. The development was conducted by researchers and informed by clients by means of prototyping. Suggestions for improvements were discussed by user organization and vendor representatives in project and work meetings. Some were implemented in a new prototype that was again subject to discussions. In total, 6 such iterations of MSI development were performed. Overall, the interface prototypes specified a common business terminology for system-to-system communication of transport activities and their relationships. For instance, sensor data from embedded systems such as gear shift metrics, maintenance timing, and fuel consumption were included to supplement a stationary and goods-centered view of transport assignments.

Over the iterations, it became evident that the architecture suggested by MSI prototypes presented the vendor organizations with a novel set of problems as existing knowledge and relations in the industry network were challenged. First, the instantiation of technology capability awareness in MSI provoked new insights into the limitations of present awareness of technologies and their potential. As an example, the service capability innovation pertaining to working time management of embedded technology such as digital tachographs was discussed. Initial MSI prototypes encapsulated an idea of relations between working time monitoring services in stationary systems and recorded data from embedded technology. This idea was instantiated in a subset of terms in MSI made available for inter-system communication. However, this provoked a reaction from the industry network as it became evident that no organization could conceptualize such relations. The two representatives of truck manufacturers noted:

This feels awfully complex, with rules and regulations and all. Considering EU and the working time directive… Wait and see I would say, or else we'll never reach the finish line. We export driver-data to enterprise systems and to other time reporting systems, such as those in France. But it's not done in real-time.

We have talked about TMS [transport management systems] and TSP [telematics service providers]. The question is: should time report go to a traditional TMS-application? We see another actor here. Not necessarily, but it could be. It gets complicated. I think that an important distinction is that of real-time. This is more about logging something. That takes more. I don't think that we'll be able to solve that here.

In the end, detailed data for working time management were removed from subsequent versions of MSI. This embedded technology fell out of scope as its capabilities could not be substantiated into service innovation. We viewed this as an example of architectural knowledge development within the industry network.

Second, the prototype development process provoked the industry network to revisit their views on the management of use contexts. With regard to user context sensitivity, several user organizations pointed to the need of localization of a number of standard business terms. In essence, this responded to the need of switching terminology to firm-specific local conditions. Thus, a separate "context schema"-mechanism was developed. This mechanism provided MSI with a potential to adapt a number of business terms by referring to a locally defined context schema in any given communication. However, the existence of such a feature in the emerging architecture prompted a discussion of who was responsible for defining and managing these local contexts. In the end, MSI was designed according to the idea that such management was the responsibility of the stationary vendors.

Third, current business models were continuously influencing MSI development. For example, it became evident that sensor data of embedded systems in use were largely seen as a vendor resource, rather than the property of the user organization. Incorporating such data in MSI threatened to make it available with considerably less effort than previously, thus opening up for service innovators primarily operating within other components. Worried about this new market logic, this prompted a hesitant stance from embedded vendors:

We should not involve the area between the telematics service provider and the truck. You [the industry network] don't control what we do or this whole way of thinking will fall to pieces. The thinking should be a generic API. Then it's up to the telematics service provider to get the information to the truck. How we do that is none of your concern. We do the formatting and it's our secret. We will never let go of that.

All data emanating from the vehicle is always stored with the telematics service provider. That's why we get into conflict here since us telematics actors feel that we can create a unique service out of this information. We do not want to give that business away to someone else. If a customer demands it, we will have to act, but we shouldn't do anything just because the data is there. I'm just afraid that we could put anything into this. And then we could remove the middle part and put all functionality into the business systems.

Indeed, these negotiations were threatening to stall the entire process. To permit a reconsideration of innovation potential and future business, customer pressure proved decisive. Such pressure could be leveraged by TRB who conceptualized the inclusion of embedded systems data in terms of potential business relations:

I think that I will have to add a customer perspective to this discussion. We are interested of managing our business data, our assignments. But we know that many of the systems sold today are hooked up to the FMS [fleet management systems]-interface, or directly to the CAN [controller area network]-bus. Thus we know that the data can be extracted. And since it can, we want it to be delivered in this format. That's a service you purchase. If you don't, you won't get it. It's optional and it's up to you to sell it to us. But we value it! That is the main reason for a hauler to buy this equipment: to lower his fuel consumption. That's where he makes his money.

The dispatchers make money from making the information management more efficient, and the hauler makes money by minimizing his costs.

The conceptualization of business potential resulted in a compromise that allowed the inclusion of embedded data relevant to a transport assignment. While on fuel consumption was included, it did not include high-resolution data used for other purposes such as vehicle maintenance and engine development. This arrangement provided vendors of embedded technology with what they considered an innovation leeway.

An important assumption in entering the second action research cycle was that a common standard would hamper proprietary interfaces' negative influence on boundary-spanning interaction. This assumption was confirmed over the process, and it was really put to test when a major stationary technology vendor threatened to leave (and eventually did) the industry network. This threat can be viewed as indicative of architectural knowledge creation at an inter-firm level that potentially would redefine the competitive logic of systems integration. During a project meeting in September 2005, the vendor abruptly declared that they were investigating whether the current MSI prototype posed an infringement of intellectual property rights in relation to their own proprietary interface and called for an immediate halt of the ongoing development:

The commercial objection is about intellectual rights issues. This is a rather peculiar community that has, under the name of a research institute, went in and gotten information and published it without any form of contract between the institute and the actors. And this is the first commercial meeting where we discuss what happens to a standard. […] Our dilemma is that our management group is demanding to know who really owns large portions of what this development process has been based on. Who owns the right to commercialize this?

This was a serious setback that threatened to derail the entire process. Indeed, progress was halted as activities were rerouted towards ascertaining the potential merits to such a claim and determining how the rest of the client system would position itself. However, after three months it became evident that their attempt at derailing the progress had in fact had the opposite effect. A technology vendor commented:

Of course, we have divergent interests, but somewhere it's all about an emerging industry. We are pawns in a large business and there's nothing else to be said about it than that this is good for the industry. It is one step closer to digitizing management, one step closer to tearing down borders of all sorts. That's why they drop out. They would rather pursue their part than the *combined needs within the industry. It's obvious that they pursue a lock-in strategy and that developing the industry goes badly with it.*

The remaining actors in the industry network issued a letter of intent to them explaining that the project would continue with or without their participation. Faced with a unified community, the stationary vendor chose to revoke initial claims. Declining to take further part, they left the industry network in November 2005, whilst not pursuing the initial threat of legal action. Mindful of the alternatives posed by individual firms pursuing component based architectural strategies, the remainder of the project group pressed on. The user organization representative (TRB) noted:

We have a window of opportunity. The alternatives are to open up for a Microsoft-like actor to charge in and decide the future for us or perhaps an endless chaos of middleware operators making copious amounts of money from integrating systems. If we don't act now, these are our remaining options.

5.3 Evaluating and specifying learning

Two test integrations using MSI were performed during the summer of 2006. IBS and Vehco systems were integrated in one setting, and Locus and Vehco in another. In both of these assessments, it became clear that the use of MSI required a change in workflow as the relationship between stationary and mobile vendors were altered. Reflecting on the evaluation project, one member of the technical staff of a stationary vendor compared his experiences with previous work utilizing proprietary interface:

Previously, we just dumped all database fields from our order registry to an XML file that is transmitted. The structure of MSI is better. Technically it's more work using MSI, of course, than to dump the order registry. But everything becomes much clearer when you get it up and running. In the beginning I doubted the standardization effort, but I think it has progressed nicely all together. I feel it could be used in all of our projects, really.

This change of practice indicated a shift from a previous overarching dominance of the stationary perspective. Rather than practicing a proprietary architectural strategy, the stationary actors involved were beginning to perceive their knowledge of technologies, use contexts, and business models as a component in a larger environment composed of other subsets. Indeed, there were more signs of a change of strategy. In August 2006, the results of the test cases were presented at the annual trade fair. On this trade fair, one of the user organizations presented their experience of using MSI. In short, the manager recognized the interface standard as a means of clarifying roles and relationships among vendors, thus facilitating requirements specification and deliverables when combining heterogeneous technologies into a coherent information environment. Following the trade fair, MSI Group received attention from trade press and road haulage companies as well as vendors previously skeptical of the endeavor.

Moreover, as a result of the MSI experience, Volvo had abandoned its attempts at competing in the stationary IT base, instead concentrating fully on their mobile and embedded component. A telematics vendor noted:

That's one of the main things: that we have gotten this community in which we can cooperate on certain levels. It shows that you must have a very clear scope when dealing with these things. In particular when there are competing activities involved. Because in the end we agree that this is not an issue of competition; we must solve this so that customers will want to buy our product and our services.[…] The vision was that we had to connect the systems to be able to deliver a total solution. No one can do everything themselves. You have to realize that we need each other to solve customer problems. Here we have had the problem that everyone tries to do everything. That's new technology.[…] If you are going to offer packaging of services spanning everything, integration is very much at the heart of innovation in service development. I think that MSI will innovate the way in which people cooperate, but also in how we deliver total solutions to our customers

In late summer 2007, the industry network was transformed into a commercial standardization organization. The MSI initiative had by then acquired the attention of trade press and was well known in the Swedish road transport industry. Taking advantage of the increasing interest, new membership applications are considered. Throughout these concluding phases, the role of the researchers was gradually phased out as actors in the industry network increasingly perceived the effort not only worthwhile, but also durable and stable. In this sense effects on the client system have potentially become sustainable.

6 Implications for Research and Strategy

The received literature on UCEs in organizational contexts examines heterogeneous and interconnected information technologies in boundary-spanning practices (Lindgren et al. 2007), customer relationships (Gershman and Fano 2006), supply chains (Roussos 2006b), and value networks (Jonsson et al. in press). In this regard, this body of literature frames UCE deployment as a complex process of aligning heterogeneous technologies with business strategy and relationships. This paper extends this stream of inquiry by providing a perspective on architectural knowledge in heterogeneous IT innovation.

6.1 THEORETICAL IMPLICATIONS

We embarked on this AR in order to address the research question as to how industries can develop the architectural knowledge necessary for establishing an industry-wide UCE. A distinguishing feature of such environments is that they are not designed de novo. Rather, they align already existing, independent, IT bases to form components of a larger architecture. Following Henderson and Clark's (1990) model of architectural innovation, we conceptualize a UCE as an assemblage of core components dependent on a common architecture. However, with the objective of explicating the emergence of architectural IT innovation in the UCE setting, we extended this framework to take into consideration the existence of multiple component IT bases. Complementing Yoo et al.'s (2005) analysis of heterogeneous yet interdependent infrastructure elements, our research model considers cases where individual components are capable of independently delivering a specific set of end user value. Such components include not only an IT base (Lyytinen and Rose 2003), but also associated component knowledge of technologies, industry relationships, and markets. The model formalizes these components and relationships into a framework with which to understand the role and nature of architectural knowledge in heterogeneous IT innovation. In doing so, the model is a contribution to the extant IT innovation literature.

The research model and its propositions were analyzed throughout two AR cycles. In this analysis, we identified and examined four dimensions of architectural knowledge that emerged in applying our model for alleviating the practical problems of the involved industry network. The four dimensions were *technology capability awareness*, *use context sensitivity*, *business model understanding*, and *boundary-spanning competence*. The first three dimensions define sub-sets of architectural knowledge, while boundary-spanning competence denotes the ability of creating such knowledge across IT bases. Technology capability awareness refers to actors' perception of the base service capability of a specific component IT base. For instance, this may refer to the know-how of mobile IT such as nomadic devices to produce applications exploiting these capabilities for the development of text messaging services. The awareness of technological capability is governed by prior experiences, or technological frames (Orlikowski and Gash 1994), pertaining to core technologies of the IT base. *Use context sensitivity* refers to the understanding of work contexts in which a specific component IT base is typically deployed. As an example, an important context for embedded technology such as diagnostics is vehicle maintenance, and knowledge of this work practice is essential for service development. This sensitivity may also encapsulate an understanding of the fact that multiple use contexts of ubiquitous computing technologies may exist (Henfridsson and Lindgren 2005). For instance, remote diagnostics data can also be used for product development purposes of the technology vendor (Lindgren et al. in press). *Business model understanding* refers to the appreciation of business opportunities afforded by applications of a component IT base (cf., Fleisch and Tellkamp 2006).

The mastery of these three dimensions of knowledge is crucial to successful heterogeneous IT innovation. However, service innovation in the UCE context entails a coupling of knowledge of independent components. While the embedded, mobile, and stationary component IT bases offer independent business solutions, they are necessary but not sufficient for UCE innovation. As our study shows, architectural knowledge is a key ingredient in UCE innovation to couple component knowledge cross the boundaries of heterogeneous components. The boundary-spanning aspect of developing a UCE architecture can be challenging for individual firms, because learning with respect to new outside information is largely a function of their prior knowledge (Cohen and Levinthal 1990). *Boundary-spanning competence* enables actors to redefine component knowledge in view of knowledge associated with other components of the architecture. Thus, it refers to practical skills and resources for engaging in collective efforts to develop architectural knowledge in an industry.

The four dimensions of architectural knowledge emerged throughout our AR project and reflect core competencies for designing UCE. We argue that these dimensions are important capabilities in heterogeneous IT innovation. These sub-sets of architectural knowledge are imperative to the creation of trading zones (Kellogg et al. 2006) in which heterogeneous actors can meet and negotiate alignment of technologies. Reflecting on the MSI case, it can be noted that the project environment worked as a physical and cognitive arena “for communities with separate innovation trajectories to negotiate, collaborate, and learn through mutual perspective making and taking” (Boland et al. 2006, p. 635). AR cycle #1’s development of communication channels and filters between industry actors in the project network enabled interaction for creation of architectural knowledge. We noted an increased appreciation of technology capability, use context, and business model as sub-sets of architectural knowledge. However, there were no significant signs of modification of component knowledge.

It was not until AR cycle #2 that boundary-spanning competence-building took off. MSI evolved into a boundary object that enabled innovation among these heterogeneous actors. It instantiated the architectural knowledge developed throughout the project, creating a new innovation cycle (cf. Yoo et al. 2005) that allowed actors to tap knowledge into their respective innovation trajectories. We experienced an occasion of redefined component knowledge as a result of the actions taken for building architectural knowledge. In sum, the MSI project involved much learning about the role and nature of architectural knowledge in linking heterogeneous actors and technologies. We are confident that our research model conceptualizes heterogeneous IT innovation, thus providing a basis for building of a more comprehensive theoretical understanding that is tested for robustness in other situations of heterogeneous IT innovation. Indeed, the model complements other IT innovation perspectives that deal with multiple actors and markets (e.g., Lyytinen and Rose 2003; Yoo et al. 2005).

Our research suggests that future inquiry would include studies on architectural knowledge, communication channels and filters, as well as the generative capacity of IT instantiations. First, the sub-sets of architectural knowledge basically represent an ontology of industry relations mediated through technology, while the boundary-spanning competence represents its epistemology. An interesting line of research would be to further examine the relation between the epistemology and ontology of architectural knowledge. The dynamism characterizing industry networks suggests that there is a dual relationship between these entities. Second, additional studies are needed to understand how to improve the communication channels and filters that link the learning taking place in the collaborative project environment of an industry network to the everyday innovation trajectories in each firm. At the component level, timing is important to align with the complex web of ongoing initiatives in the industry network, suggesting the need to understand how the architecture can be coordinated with innovation trajectories. Finally, further studies are needed focusing on the role of boundary objects in the creation of architectural knowledge. It can be established that such objects are imperative to foster boundary-spanning competence. Yet it is unclear how differences in their generative capacity play out in the innovation game. Does it matter if the boundary object is a negotiated XML interface? Would it be different if the boundary object was a committee-based communications standard?

6.2 STRATEGY IMPLICATIONS

Paying tribute to the dual goal of AR, it is necessary to convey the practical contributions to the clients of our research. A significant and sustainable outcome is the establishment of the MSI Group, which is a commercial consortium of vendors of embedded, mobile, and stationary transport systems, as well as truck manufacturers and user organizations governing an interface standard that is now available to the transport industry. In fact, there are examples of transport organizations that have completed MSI-based integration projects. Several vendors are currently implementing the standard in their software packages and considering the implications for business strategy. For instance, in pursuing a new telematics strategy, Volvo Trucks is currently drawing on the architectural knowledge generated in the AR project. This strategy enables their embedded telematics systems be part of larger architectures of multiple components belonging to vendors of ERP, navigation, and order management systems.

The MSI Group is now entering a stage where new firms are aligned to the consortium. In particular, negotiations are underway with new types of actors such as mobile network operators. Underlined by the newly appointed president, the consortium’s challenge here is not primarily to explain the technical interface but to secure that the knowledge developed be successfully shared with new entrants. Thus, the architectural knowledge sub-sets identified throughout the AR project will be significant to further network expansion.

Our research shows that a heterogeneous environment can be stabilized by collectively designing and accepting an architectural design in which crucial IT bases are viewed as independent components, each adding clearly defined capabilities to the overall architecture of the environment. There are a number of strategic implications that reach beyond our AR context. First, an open architecture should not pose an immediate threat to perceived core markets of any component IT base. It is therefore imperative to balance the need for open core component capabilities and requirements of innovation leeway for individual firms within their core IT base. This is typically achieved by black-boxing certain aspects of the component IT bases. Second, it is useful to develop boundary definitions between components of an architecture with respect to technology capabilities, use contexts, and business models. In doing so, architectural knowledge emerges as an increased collective capability to appreciate the conditions present in other components. Third, in industries lacking a dominant actor as a locus of innovation, a strategic task is to establish a political platform that is perceived neutral enough to facilitate the emergence of architectural knowledge. Our experience is that managers should consider aligning with universities, research institutes, or industry association for establishing such neutral grounds.

Finally, user organizations should be invited to balance the diverging market strategies found in the involved IT bases by formulating scenarios and supplying cases. By increasing client participation, struggles between rival proprietary architectures can be defused.

7 REFERENCES

Abowd, G.D., Atkeson, C.G., Hong, J., Long, S., Kooper, R., and Pinkerton, M. "Cyberguide: A mobile context-aware tour guide," *Wireless Networks* (3) 1997, pp 421-433.

Abowd, G.D., and Mynatt, E.D. "Charting Past, Present, and Future Research in Ubiquitous Computing," *ACM Transactions on Computer-Human Interaction* (7:1) 2000, pp 29-58.

Andersson, M., Lindgren, R. "The Mobile-Stationary Divide in Ubiquitous Computing Environments: Lessons from the Transport Industry," *Information Systems Management* (22:4) 2005, pp 65-79.

Avison, D., Baskerville, R., and Myers, M. "Controlling Action Research Projects," *Information Technology & People* (14:1) 2001, pp 28-45.

Baskerville, R., and Myers, M.D. "Special Issue on Action Research in Information Systems: Making IS Research Relevant to Practice - Foreword," *MIS Quarterly* (28:3) 2004, pp 329-335.

Baskerville, R.L., and Wood-Harper, A.T. "A Critical Perspective on Action Research as a Method for Information Systems Research," *Journal of Information Technology* (11) 1996, pp 235-246.

Baskerville, R.L., and Wood-Harper, A.T. "Diversity in Information Systems Action Research Methods," *European Journal of Information Systems* (7:2) 1998, pp 90-107.

Becker, S.W., and Whisler, T.L. "The Innovative Organization: A Selective View of Current Theory and Research," *Journal of Business* (40) 1967, pp 462-469.

Berg Insight. “Fleet Management and Wireless M2M”, M2M Research Series 2006 (www.berginsight .com).

Boland, R.J., Lyytinen, K., and Yoo, Y. "Wakes of Innovation in Project Networks: The Case of Digital 3-D Representations in Architecture, Engineering, and Construction," *Organization Science* (18:4) 2007, pp 631-647.

Braa, J., Monteiro, E., and Sahay, S. "Networks of Action: Sustainable Health Information Systems Across Developing Countries," *MIS Quarterly* (28:3) 2004, pp 337-362.

Chesbrough, H. *Open Innovation: The New Imperative for Creating and Profiting from Technology* Harvard Business School Press, Boston, MA, 2006.

Chesbrough, H., Vanhaverbeke, W., and West, J. (eds.) *Open Innovation: Researching a New Paradigm*. Oxford University Press, Oxford, 2006.

Cohen, W.M., Levinthal, D.A. "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* (35:1) 1990, pp 128-152.

Daft, R.L. "A Dual-Core Model of Organizational Innovation," *Academy of Management Journal* (21:2) 1978, pp 193-210.

Daft, R.L., and Weick, K.E. "Towards a Model of Organizations as Interpretation Systems," *Academy of Management Review* (9) 1984, pp 284-295.

Davison, R.M., Martinsons, M.G., and Kock, N. "Principles of canonical action research," *Information Systems Journal* (14) 2004, pp 65-86.

Dewar, R.D., and Dutton, J.E. "The Adoption of Radical and Incremental Innovations: An Empirical Analysis," *Management Science* (32:11) 1986, pp 1422-1433.

Fleisch, E., and Tellkamp, C. "The Business Value of Ubiquitous Computing Technologies," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*, G. Roussos (ed.), Springer, London, 2006, pp. 93-113.

Gershman, A., and Fano, A. "Ubiquitous Services: Extending Customer Relationship Management," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*, G. Roussos (ed.), Springer, London, 2006, pp. 75-92.

Grindley, P. *Standards, Strategy, and Policy: Cases and Stories* Oxford University Press, New York, 1995.

Grover, V., Fielder, K., and Teng, J. "Empirical Evidence on Swanson's Tri-Core Model of Information Systems Innovation," *Information Systems Research* (8:3) 1997, pp 273-287.

Hage, J. *Theories of Organizations*, John Wiley & Sons, New York, 1980.

Hanseth, O. and Monteiro, E. “Inscribing Behavior in Information Infrastructure Standards”. *Accounting, Management & Information Technology*,” 7 (4) 1997, pp 183-211.

Henderson, R.M., Clark, K.B. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly* (35) 1990, pp 9-30.

Henfridsson, O., and Lindgren, R. "Multi-Contextuality in Ubiquitous Computing: Investigating the Car Case through Action Research," *Information and Organization* (15:2) 2005, pp 95-124.

Jonsson, K., Westergren, U.H., and Holmström, J. "Technologies for Value Creation: An Exploration of Remote Diagnostics Systems in the Manufacturing Industry," *Information Systems Journal*, in press.

Kellogg, K.C., Orlikowski, W.J., and Yates, J. "Life in the Trading Zone: Structuring Coordination Across Boundaries in Postbureaucratic Organizations," *Organization Science* (17:1) 2006, pp 22-44.

Lindgren, R., Andersson, M., and Henfridsson, O. "Multi-Contextuality in Boundary-Spanning Practices," *Information Systems Journal*, in press.

Lindgren, R., Henfridsson, O., and Schultze, U. "Design Principles for Competence Management Systems: A Synthesis of an Action Research Study," *MIS Quarterly* (28:3) 2004, pp 435-472.

Lyytinen, K., and Yoo, Y. "Research Commentary: The Next Wave of Nomadic Computing," *Information Systems Research* (13:4) 2002a, pp 377-388.

Lyytinen, K., and Yoo, Y. "Issues and Challenges in Ubiquitous Computing," *Communications of the ACM* (45:12) 2002b, pp 63-65.

Lyytinen, K., and Rose, G.M. "The Disruptive Nature of Information Technology Innovations: The Case of Internet Computing in Systems Development Organizations," *MIS Quarterly* (27:4) 2003, pp 557-595.

March, S., Hevner, A., and Ram, S. "Research Commentary: An Agenda for Information Technology Research in Heterogeneous and Distributed Environments," *Information Systems Research* (11:4) 2000, pp 327-341.

Markus, M.L., Majchrzak, A., and Gasser, L. "A Design Theory for Systems That Support Emergent Knowledge Processes," *MIS Quarterly* (26:3) 2002, pp 179-212.

Mathiassen, L. "Collaborative Practice Research," *IT & People* (15:4) 2002, pp 321-345.

McKay, J., and Marshall, P. "The Dual Imperatives of Action Research," *IT & People* (14:1) 2001, pp 46-59.

Orlikowski, W.J., and Gash, D.C. "Technological Frames: Making Sense of Information Technology in Organizations," *ACM Transactions on Information Systems* (12:2) 1994, pp 174-207.

Rogers, E.M. *Diffusion of Innovations*, (4 ed.) Free Press, 1995.

Roussos, G. (ed.) *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*. Springer, London, 2006a.

Roussos, G. "Supply Chain Management Standards in Ubiquitous Commerce," in: *Ubiquitous and Pervasive Commerce: New Frontiers for Electronic Business*, G. Roussos (ed.), Springer, London, 2006b, pp. 15-31.

Sheremata, W.A. "Competing through Innovation in Network Markets: Strategies for Challengers," *Academy of Management Review* (29:3) 2004, pp 359-377.

Soh, P.-H., Roberts, E.B. "Networks of innovators: a longitudinal perspective," *Research Policy* (32) 2003, pp 1569-1588.

Star, S.L., and Ruhleder, K. "Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces," *Information Systems Research* (7:1) 1996, pp 111-134.

Susman, G., and Evered, R. "An Assessment of the Scientific Merits of Action Research," *Administrative Science Quarterly* (23) 1978, pp 582-603.

Swanson, E.B. "Information Systems Innovation among Organizations," *Management Science* (40:9) 1994, pp 1069-1092.

Sørensen, C., and Yoo, Y. "Socio-Technical Studies of Mobility and Ubiquity," in: *Designing Ubiquitous Information Environments: Socio-Technical Issues and Challenges*, C.

Sørensen, Y. Yoo, K. Lyytinen and J.I. DeGross (eds.), Springer, New York, 2005, pp. 1-14.

Teece, D.J. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Research Policy* (15) 1986, pp 285-305.

Topi, H. "From the Editors," *Information Systems Management* (22:4) 2005, pp 5-6.

Van de Ven, A.H. "Running in Packs to Develop Knowledge-Intensive Technologies," *MIS Quarterly* (29:2) 2005, pp 365-378.

von Hippel, E. "'Sticky Information' and the Locus of Problem Solving: Implications for Innovation," in: *The Dynamic Firm,* A.D. Chandler, P. Hagström, and Ö. Sölvell (eds.), Oxford University Press, Oxford, 1998, pp. 60-77.

Weiser, M. "Some Computer Science Issues in Ubiquitous Computing," *Communications of the ACM* (36:7) 1993, pp 75-84.

Yoo, Y., and Lyytinen, K. "Social Impacts of Ubiquitous Computing: Exploring Critical Interactions between Mobility, Context and Technology - A Special Issue for Information and Organization," *Information and Organization* (15:2) 2005, pp 91-94.

Yoo, Y., Lyytinen, K., and Yang, H. "The Role of Standards in Innovation and Diffusion of Broadband Mobile Services: The Case of South Korea," *Journal of Strategic Information Systems* (14) 2005, pp 323-353.

Gothenburg Studies in Informatics

ISSN 1400-741X (print), ISSN 1651-8225 (online)

1. Ulf Sundin. A logic programming approach to information modeling and database design, May 1990. (Licentiate Thesis).
2. Thanos Magoulas and Kalevi Pessi. En studie om informationssystemsarkitekturer (in Swedish), February 1991. (Licentiate Thesis).
3. Peter Nordenstam. Individbaserade relativt öppna informationssystem (in Swedish), February 1990. (Licentiate Thesis).
4. Bo Dahlbom and Lars Mathiassen. Struggling with quality; The philosophy of developing computer systems, August 1991. (Revised edition: Computers in context; The philosophy and practice of systems design, Oxford: Blackwell, 1993.)
5. Börje Langefors. Essays on infology. Summing up and planning for the future, Edited by Bo Dahlbom, August 1993.
6. Bo Dahlbom (Ed.). The infological equation. Essays in honor of Börje Langefors, March 1995.
7. Bo Dahlbom, Frederik Kämmerer, Fredrik Ljungberg, Jan Stage and Carsten Sørensen. Proceedings of the 18th Information Systems Research Seminar in Scandinavia, June 1995.
8. Bo Dahlbom, Fredrik Ljungberg, Urban Nuldén, Kai Simon, Jan Stage and Carsten Sørensen. Proceedings of the 19th Information Systems Research Seminar in Scandinavia, June 1996.
9. Agneta Ranerup. Användarmedverkan med representanter (in Swedish), August 1996. (Doctoral Thesis).
10. Ole Hanseth. Information technology as infrastructure, November 1996. (Doctoral Thesis).
11. Fredrik Ljungberg. Networking, September 1997. (Doctoral Thesis).
12. Jan Ljungberg. From workflow to conversation, October 1997. (Doctoral Thesis).
13. Thanos Magoulas and Kalevi Pessi. Strategisk IT-management (in Swedish), March 1998. (Doctoral Thesis).
14. Fredrik Ljungberg (Ed.). Informatics in the next millennium. Essays in honor of Bo Dahlbom, June 1999.
15. Urban Nuldén. e-ducation, May 1999. (Doctoral Thesis).
16. Lars Erik Holmquist. Breaking the Screen Barrier, May 2000. (Doctoral Thesis).

17. Nina Lundberg. IT in Healthcare - Artifacts, Infrastructures and Medical Practices, May 2000. (Doctoral Thesis).
18. Henrik Fagrell. Mobile Knowledge, October 2000. (Doctoral Thesis).
19. Staffan Björk. Flip Zooming - The development of an information visualization technique, October 2000. (Doctoral Thesis).
20. Johan Redström. Designing Everyday Computational Things, May 2001. (Doctoral Thesis).
21. Dick Stenmark. Designing the new Intranet, March 2002. (Doctoral Thesis).
22. Pouya Pourkomeylian. Software Practice Improvement, March 2002. (Doctoral Thesis).
23. Rikard Lindgren. Competence Systems, June 2002. (Doctoral Thesis).
24. Ulrika Lundh Snis. Codifying Knowledge, October 2002. (Doctoral Thesis).
25. Lars Svensson. Communities of Distance Education, December 2002. (Doctoral Thesis).
26. Kai Simon. BPR in the Pharmaceutical Industry, April 2003. (Doctoral Thesis).
27. Per Dahlberg. Local Mobility, May 2003. (Doctoral Thesis).
28. Alexandra Weilenmann. Doing Mobility, June 2003. (Doctoral Thesis).
29. Carina Ihlström. The Evolution of a New(s) Genre, September 2004. (Doctoral Thesis).
30. Antonio Cordella. Information Infrastructures in Action, November 2004. (Doctoral Thesis).
31. Helena Holmström. Community-Based Customer Involvement for Improving Packaged Software Development, November 2004. (Doctoral Thesis).
32. Christian Hardless. Designing Competence Development Systems, March 2005. (Doctoral Thesis).
33. Andreas Nilsson. Sport Informatics – Exploring IT Support for Spectators at Sporting Events, November 2005. (Doctoral Thesis).
34. Johan Lundin. Talking about Work – Designing Information Technology for Learning in Interaction, November 2005. (Doctoral Thesis).
35. Agneta Nilsson. Contextual Implementation of Organizational Networking Systems, August 2006. (Doctoral Thesis).
36. Mathias Klang. Disruptive Technology – Effects of Technology Regulation on Democracy, October 2006. (Doctoral Thesis).
37. Ulrika Josefsson. Coping Online – Patients' Use of the Internet, February 2007. (Doctoral Thesis).
38. Magnus Holmqvist. Developing And Implementing IS/IT in Aftermarket Logistics, June 2007. (Doctoral Thesis).

39. Jonas Landgren. Designing Information Technology For Emergency Response, September 2007. (Doctoral Thesis).

40. Magnus Andersson. Heterogeneous IT Innovation – Developing Industrial Architectural Knowledge, October 2007. (Doctoral Thesis)